National Park Service
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Geologic Resources Division
Denver, Colorado

Dinosaur National Monument

Geologic Resource Evaluation Report

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Executive Summary

This report has been developed to accompany the digital geologic map produced by Geologic Resource Evaluation staff for Dinosaur National Monument. It contains information relevant to resource management and scientific research.

Dinosaur National Monument (NM) is internationally known as a repository of significant fossil resources. Located on the Utah- Colorado border, Dinosaur NM is one of eight national park units established primarily for the protection of significant fossil resources. At Dinosaur these resources include the thousands of dinosaur bones that are now housed in the Dinosaur Visitor Quarry. These bones were entombed about 150 Ma during the Late Jurassic Period. They became part of the flat- lying strata that were later uplifted and tilted during the Laramide Orogeny to an angle of about 67°. Today the bones form a spectacular display on one wall of the quarry.

The Dinosaur Quarry is world- renown not only for the quantity of fossil material (over 350 tons of fossils and attached rock were removed from 1909 to 1924) but also for the quality of the dinosaur remains found there. Eleven different types of dinosaurs, from giant herbivorous Sauropods to voracious carnivores, have been discovered at the quarry. Several relatively complete, articulated skeletons have been removed from the quarry. The 21.79 m (71.5 ft) skeleton of *Apatosaurus louisae* (formerly known as Brontosaurus), for example, is one of the most complete dinosaur skeletons ever found. Bones found at Dinosaur NM come in a variety of sizes and shapes from the thick, dense thighbones of Sauropods to delicate, intact skulls, teeth, and tail tip vertebrae. The Dinosaur Quarry is a not only a remarkable sight for dinosaur enthusiasts but it also provides scientists new insights into dinosaur behavior and the ecosystem in which they lived.

Dinosaur National Monument encompasses more area than just the Dinosaur Quarry, containing spectacular canyons cut by the Green and Yampa Rivers. Rather than flowing around the nose of the east- west trending Uinta Mountains, these rivers flow through the mountains exposing strata deformed during the Laramide Orogeny about 70- 40 Ma. Canyon walls reveal textbook examples of folded and faulted rocks formed during the past 2 billion years.

During the Late Jurassic and Cretaceous, volcanoes erupted on the western margin of the North American continent and ejected volcanic ash into the atmosphere. When the ash settled, it mixed with fine sediments and groundwater to form a type of clay called bentonite consisting mostly of the clay mineral montmorillonite. Bentonite has the capacity to accept water into its structure and swell when wet and to expel water from its structure and shrink upon drying. This shrink and swell capacity of bentonite can cause havoc with roads, buildings, and infrastructures such as pipelines and septic systems, presenting challenges to park managers.

Current fluvial processes associated with the Green and Yampa Rivers may also present challenges due to erosion and flash flooding. Cliffs carved into the Weber Sandstone may be undercut, causing cliff collapse. Cliff collapse, erosion, and sediment influx from tributary streams create ever- changing fluvial geomorphic landscapes that demand the attention of park resource management.

A Geologic Resources Inventory workshop held at Dinosaur in 1998 identified issues of primary importance to resource managers. These issues included:

- Slumps in existing Morrison Formation landslide materials along the Harpers Corner road creating maintenance and traffic hazards
- Green River cutbank erosion into the Mancos Shale along the quarry entrance road near the park boundary
- Cub Creek incision of several meters into older valley fill deposits where the road crosses the stream
- Green River cutbank erosion and the relocation options for the Echo Park campground
- Expanding, contracting, and shifting Morrison Formation substrate causing damage to the Quarry Visitor Center
- Foundation movement issues at the Headquarters building in Colorado
- The need for a geologic hazards map

Research needs and potential research projects were also discussed at the workshop and included:

- Association of rare plants with certain geologic strata and geomorphic surfaces
- Comprehensive, multidisciplinary study of the Cedar Mountain Formation to gain significant understanding of the paleoenvironments of that time period
- Long- term preparation and curation of specimens
- Hydrogeology and geomorphology of Cub Creek and other stream restoration projects
- Juniper tree age dating and correlation to the past climate record

Geologic features of importance to staff at Dinosaur NM include the following:

- Dinosaur quarry
- Other localities of type specimens of fossils
- The canyons of Dinosaur
- Weber Sandstone and Steamboat Rock
- Type Localities of the Lodore Formation and Brown's Park Formation
- Laramide Structures

From Split Mountain to Lodore Canyon and the Yampa Plateau, the strata in Dinosaur display a record of geologic time that spans about 2 billion years. Dinosaur National Monument contains one of the most complete stratigraphic columns exposed in the National Park System. The Uinta Mountains contain significant clues to the structural history of the Rocky Mountains as well. The rocks are primarily sedimentary and they contain significant information that reveals and helps unravel the complex and dynamic history of Earth.

Introduction

The following section briefly describes the regional geologic setting and the National Park Service Geologic Resource Evaluation Program.

Purpose of the Geologic Resource Evaluation Program

Geologic resources serve as the foundation of park ecosystems and yield important information for park decision making. The National Park Service Natural Resource Challenge, an action plan to advance the management and protection of park resources, has focused efforts to inventory the natural resources of parks. The geologic component is carried out by the Geologic Resource Evaluation (GRE) Program administered by the NPS Geologic Resources Division.

The goal of the GRE Program is to provide each of the identified 270 "Natural Area" parks with a digital geologic map, a geologic evaluation report, and a geologic bibliography. Each product is a tool to support the stewardship of park resources and each is designed to be user friendly to non- geoscientists.

The GRE teams hold scoping meetings at parks to review available data on the geology of a particular park and to discuss the geologic issues in the park. Park staff are afforded the opportunity to meet with the experts on the geology of their park. Scoping meetings are usually held for individual parks although, some meetings address an entire Vital Signs Monitoring Network.

General Information

Dinosaur National Monument straddles the Utah-Colorado border in northwest Colorado and northeast Utah (figure 1). The Monument covers about 210,278 acres (328 sq. mi. or 852 sq. km.). Visitation in fiscal year 2002 was 299,622. Dinosaur NM is both a park with a world- famous dinosaur quarry that most people come to visit, and also a park with spectacular canyons of the Green and Yampa rivers.

The Dinosaur Quarry Visitor Center is located north of the Green River in Utah. The Quarry is 11 km (7 mi) north of Jensen, Utah, on Utah State Highway 149. Thousands of dinosaur bones that were entombed 150 Ma during the Late Jurassic Period have been discovered in this area of the park. Dinosaur NM is one of eight National Park Service units established primarily to protect significant fossil resources.

Monument Headquarters and Visitor Center are located 1.6 km (1 mi) east of the town of Dinosaur, Colorado, just off U.S. Highway 40. There are no dinosaur bones in this part of the park. The Visitor Center provides information to the public about the quarry and about the canyon country of the park.

Early Explorations

At least 7,000 and perhaps 10,000 years ago, paleo-Indians hunted big game in the Dinosaur region. About 1,800 years ago, the Fremont culture entered the area and grew corn, beans, and squash as well as engaging in hunting and gathering. They stayed until drought and crop failures drove them out about 700 years ago (Kiver and Harris, 1999). In addition to rock shelters and numerous other artifacts in the monument, the Fremont people left spectacular pictographs and petroglyphs on rock walls in the monument.

The Shoshone, who also practiced a hunting and gathering lifestyle, were the first people to reoccupy the area a few hundred years ago. In 1825 William Ashley floated through the dangerous canyons of the Green River with a small party of trappers. They were the first individuals known to do so. Major John Wesley Powell repeated the feat in 1869 and continued down the Green River to its confluence with Colorado River. He and his men were the first to navigate both canyons of the Green and Colorado rivers.

In the late 1800s, the American public became enamored with the remains of dinosaurs. Paleontologists eagerly explored the western United States looking for bones to take back to their respective colleges, universities, or museums. The treachery, competition, and frantic desire to find (and name) the next unique species during these "Dinosaur wars" make for interesting reading.

In 1908 Earl Douglas and W.J. Holland, director of the Carnegie Museum, found a magnificent dinosaur thighbone and other evidence of dinosaurs in northeastern Utah. Douglas returned the following year to the Uinta Mountains and spent months scouring the countryside, but he found no extraordinary bone deposit.

On August 19, 1909, Douglas found eight large, articulated dinosaur vertebrae in the exact position they had occupied in the living animal. These eight bones were the first of thousands that would eventually be removed from the greatest dinosaur quarry ever discovered.

Prior to Douglas' discovery, very few dinosaur bones had been found intact and even fewer complete skeletons had been uncovered. Douglas' dinosaur proved to be an *Apatosaurus* of exceptional size and completeness. His discovery proved for the first time that *Apatosaurus* had a very long tail with a so- called "whip lash" on the end. This anatomical surprise was one of many that revolutionized dinosaur paleontology.

Several years after operations began at the quarry, the government opened the area for settlement. To Douglas, Holland, and their associates, this meant that a speculator could locate a claim on the quarry property and acquire its vast bone deposits for private gain. Douglas filed a claim on behalf of the Carnegie Museum for the mineral rights to the land, but government officials disallowed the claim on the grounds that dinosaur bones could not be considered minerals in nature under the General Mining Law of 1872. Holland traveled to Washington, D.C., to confer with his old friend Charles Doolittle Walcott, a renowned paleontologist who also happened to be the Secretary of the Smithsonian Institution.

Walcott brought this issue to the attention of President Woodrow Wilson and on October 4, 1915, President Wilson set aside 80 acres surrounding the quarry as a national monument. In 1938, the monument was expanded to include the rugged canyons of the Green and Yampa rivers.

With the financial support of Andrew Carnegie, Douglas collected more than 350 tons of dinosaur bones and other fossils from the dinosaur quarry from 1909 to 1923. When the Carnegie operations ceased, the Smithsonian Institution was invited to remove some remaining important groups of bones, and in 1923, they shipped 33 boxes of fossil bones to Washington. Also in 1923, Douglas supervised teams from the University of Utah that removed an *Allosaurus* skeleton, a partial skeleton of a juvenile Sauropod, parts of two *Stegosaurus* skeletons, and an excellent *Barosaurus* skeleton (McIntosh, 1977). Construction of the Dinosaur Quarry Visitor Center began in 1957 and it was opened to the public on June 1, 1958.

Technicians at the park, Jim Adams and Tobe Wilkins, uncovered and prepared the dinosaur bones that the visitors see today. Over 2000 bones stand out in relief on the quarry face, thanks in large part to the dedication and perseverance of these two individuals.

General Geologic Setting

Dinosaur National Monument is located on the eastern end of the Uinta Mountains, a broad anticline formed during the Laramide Orogeny (about 70- 40 Ma). The Uinta Mountains are the topographic expression of a regional anticline or arch, known as the Uinta arch. They contain abundant folds and faults that developed during the Laramide mountain building event (figure 2). The Uinta Mountains are also one of the few east- west trending mountain ranges in the western United States.

Erosion by the Green and Yampa rivers cut the canyons in the monument and exposed folded and faulted rocks formed during the past 2 billion years (Kiver and Harris, 1999). Seeming to defy logic, the Green and Yampa rivers converge at the east end of the Uinta Mountains and flow through the mountain structure rather than around the topographically lower east end of the mountains.

The Green River is interpreted as a superposed stream (Hanson, 1986). The Green and Yampa rivers cut sinuous, meandering stream channels into the flat- lying Tertiary strata that had buried the older Uinta arch. When they encountered the folded strata in the anticline, the streams continued to cut down through the soft sedimentary rocks. Eventually the meanders became entrenched, and the rivers continued to cut down through the dense, hard rocks of the Precambrian core of the anticline.

Precambrian, Paleozoic, and Mesozoic strata are found at Dinosaur National Monument. The billion- year- old Uinta Mountain Group, consisting of metasediments, are exposed in the core of the Uinta arch and the Paleozoic and Mesozoic strata are laid out like pages of a book on the flanks of the eroded anticline. Dinosaur bones are primarily found in the Jurassic- age (about 150 Ma) Morrison Formation.

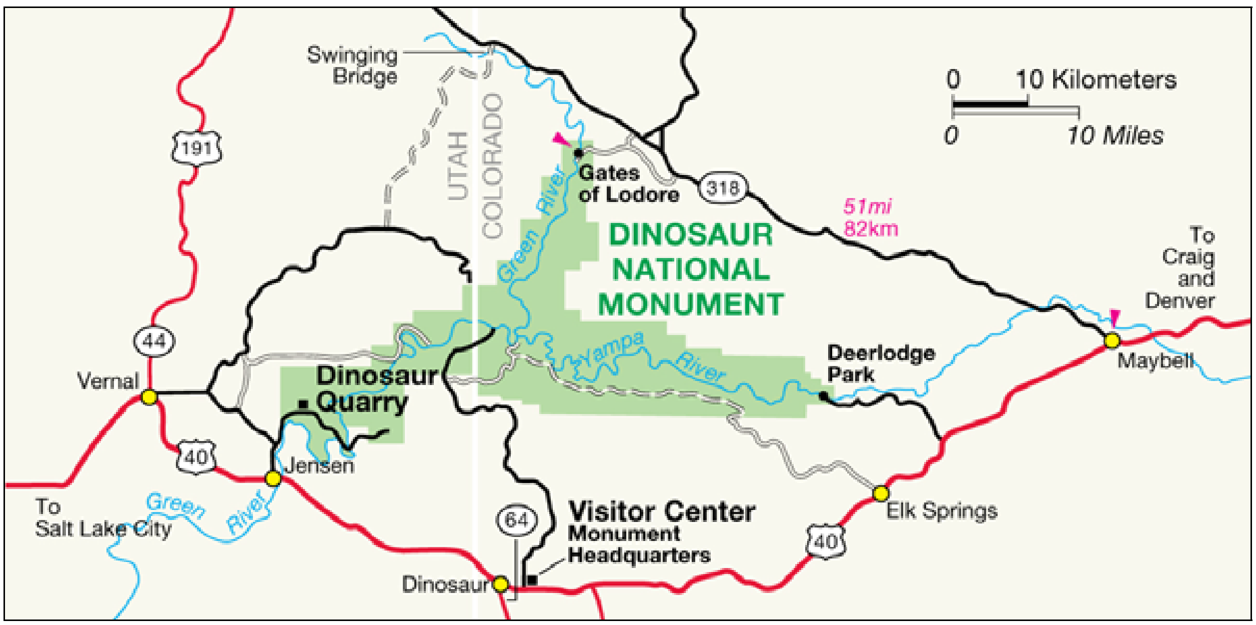

Figure 1. Location Map of Dinosaur National Monument.

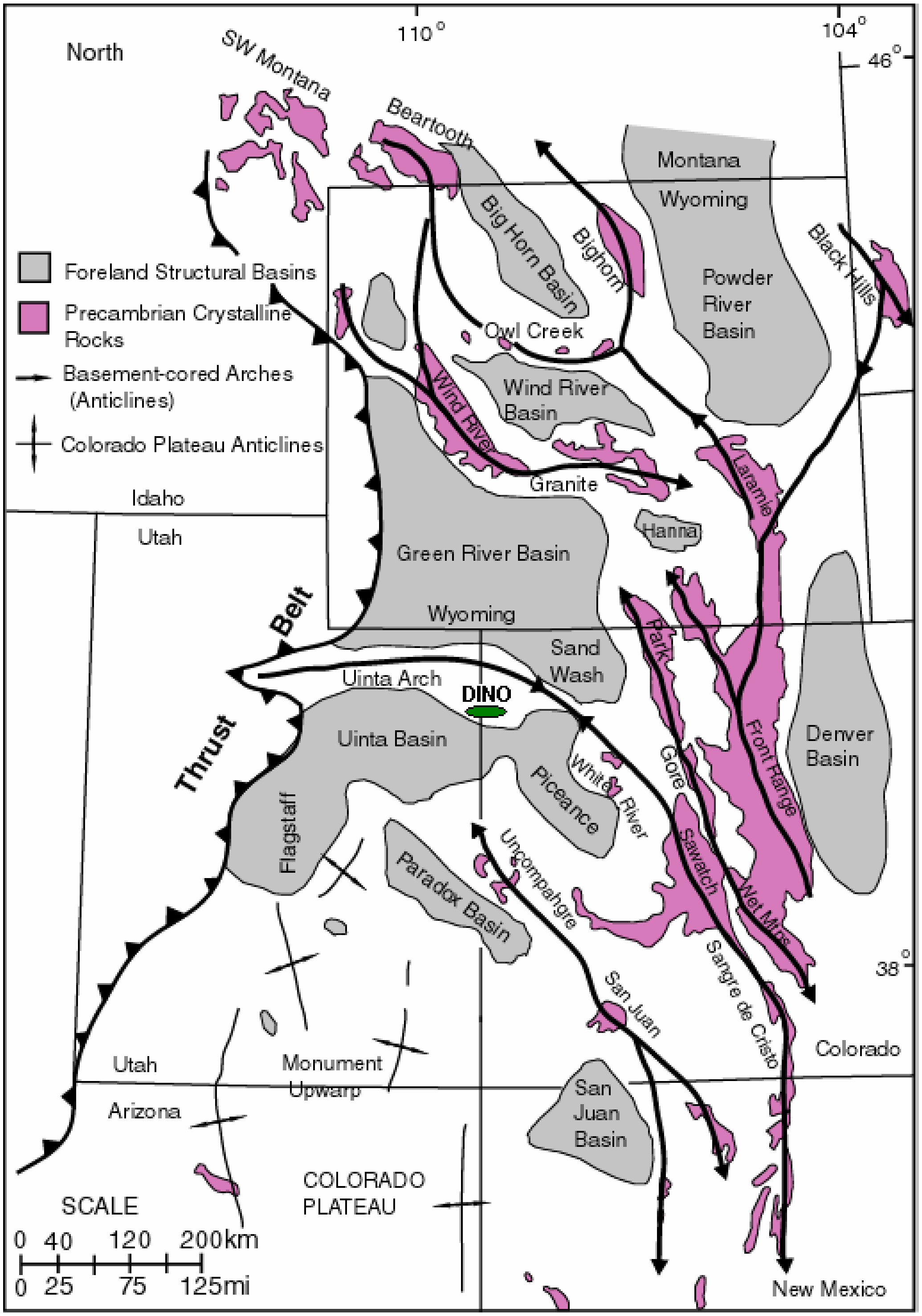

Figure 2. Laramide tectonic map showing the basement-cored arches and Thrust Belt that borders the Colorado Plateau to the west. Modified from Gregson and Chure (2000).

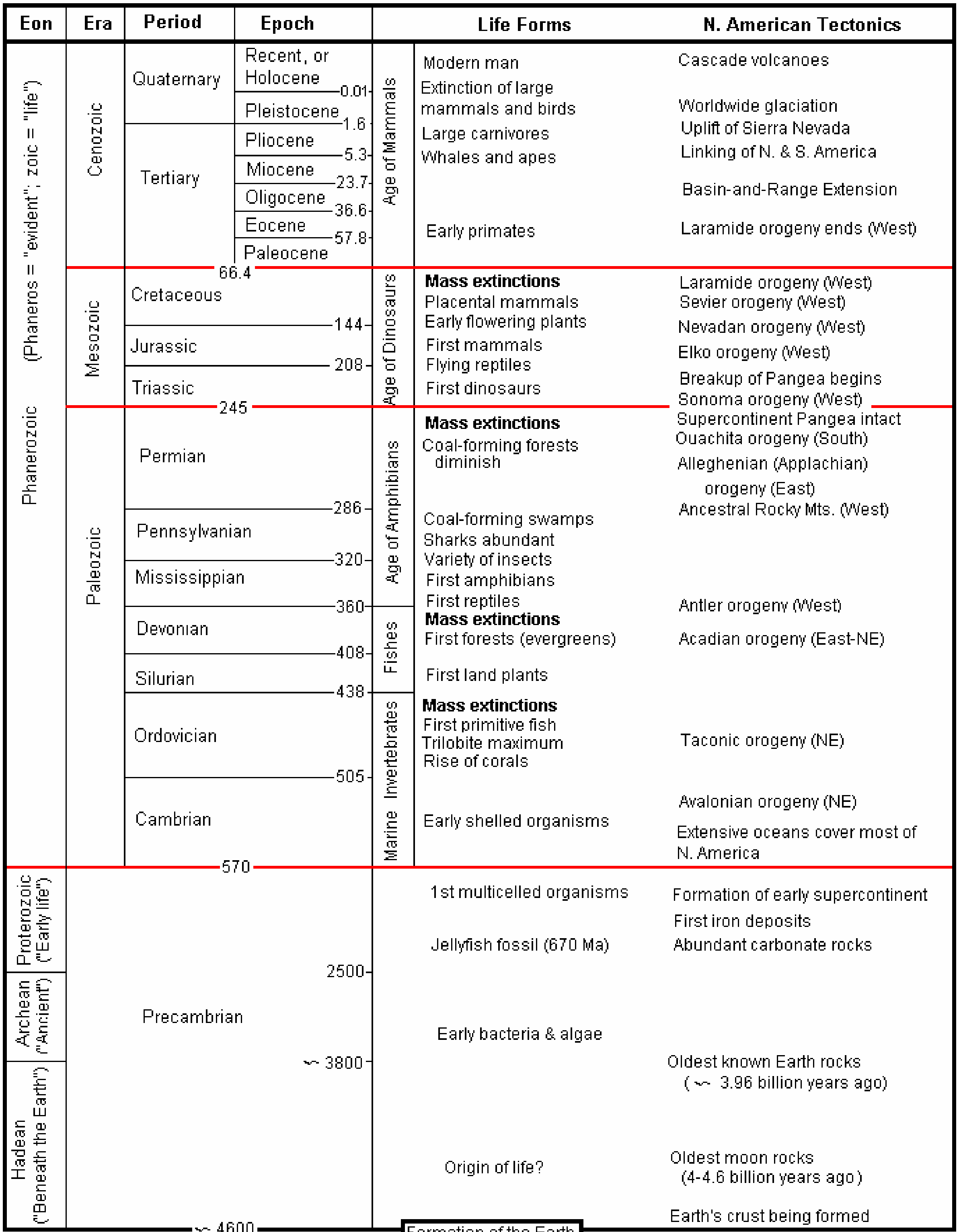

Figure 3. Geologic time scale. Red lines indicate major unconformities between eras. Absolute ages shown are in millions of years. Scale is from the United States Geological Survey.

Geologic Issues

A Geologic Resource Evaluation scoping session was held for Dinosaur National Monument, August 10- 11, 1998, to discuss geologic resources, to address the status of geologic mapping, and to assess resource management issues and needs. The following section synthesizes the scoping results, in particular, those issues that may require attention from resource managers.

Potential Geologic Hazards

A geologic resources workshop held at Dinosaur National Monument in 1998 (Appendix B) identified the following geologic hazards that affect the monument. These hazards are especially significant with regards to maintenance of park roads and buildings.

- Slumps
- Stream bank erosion
- Stream incision
- Bentonitic soils

Other issues at Dinosaur

- Abandoned mine workings
- Caves
- Adjacent mineral development

Slumps in existing landslide materials create maintenance and traffic hazards in several areas along the Harpers Corner road. Landslide material is mostly derived from the Jurassic Morrison Formation. To alleviate this problem, Dinosaur maintenance is considering relocating the roadways to the crests of associated ridges.

Mancos Shale forms the relatively flat plain leading into the dinosaur quarry in Utah. The Green River is actively eroding its cutbank along the quarry entrance road near the park boundary. Maintenance staff at Dinosaur NM have been armoring the eroded areas with riprap in an attempt to stall further cutbank erosion, but only for a limited time.

At the workshop, the "only permanent solution" discussed was to move the road to the opposite bank of the Green River, a solution with engineering and political issues. Stream restoration projects throughout the country, including one on the Yampa River in Steamboat Springs, Colorado, have shown that bank erosion can be controlled while sustaining the ecological health of a stream by relocating the channel of the river away from the cutbank, eliminating cutbank erosion. Park management may wish to consider a stream restoration project as a possible solution for Green River erosion.

The existing campground at Echo Park is also located on a cutbank of the Green River just below its confluence with the Yampa River. Participants at the workshop discussed the possibility of relocating the campground away from the river on the west side of Pool Creek Canyon to take advantage of the tree cover. This location, however, has a greater risk of flash floods and debris flows. A second alternative site is available on the east side of the creek and canyon, but unfortunately, this second site has no tree cover.

Cub Creek has incised its channel several meters into older valley fill deposits where the Cub Creek road crosses the stream. In the spring of 1998, high stream flow eroded around the end of a beaver dam upstream and flow was directed against the Cub Creek road embankment. Park maintenance redirected the flow back to the main channel through a culvert under the road and armored the upstream portion of the roadbed with riprap. Nevertheless, the stream rapidly silted- in upstream of the barrier, indicating that, although entrenched, the stream still carries a high sediment load. A comprehensive study of the hydrology and geomorphology of this area would aid in restoring the channel geometry and fluvial regime existing prior to entrenchment.

Expanding, contracting, and shifting substrate beneath the Quarry Visitor Center has caused major damage to the building. Although the quarry face appears to be stable, the central part of the structure is sinking and has sustained offsets ranging from several inches to a foot or more. The obvious floor deformation and tilting of support beams and windows suggest that the structural integrity of the building has been compromised. The building is located on the Morrison Formation which contains bentonite, a clay that swells and contracts in response to changes in water content.

Park maintenance has attempted to isolate the plumbing in the building and to keep the roof in good condition to limit the amount of water that can infiltrate under the building, but the problem persists. The spiral walkway has been reinforced but must continually be monitored for movement. Swelling clays have also deformed the parking lot and sidewalk outside the building. A comprehensive engineering study has never been undertaken. The quarry building is a historic structure, therefore approval must be obtained for any architectural modifications. Although less severe, similar foundation and movement issues exist at the headquarters building.

A geologic hazards map is needed for park planning and maintenance staff. This was discussed at the workshop but not in detail.

Two abandoned mines have been identified in Dinosaur. The Mantle Mine, an abandoned copper mine, had four adits and two shafts associated with it. These were blasted closed by the State of Colorado in 1988. There are two "outlier" openings. One is apparently a very short adit considered hazardous because of unstable rock. Another adit is near an access road. Although the area is in a remote part of the park with little visitation, both of these openings may need to be closed.

Another mine opening, the Shepard Mine, was identified on a map as being west of and "several draws over from" the Mantle Mine (Burghardt, per. com). These should be examined for possible closure in the future. Bat habitat does not appear to be an issue at either mine.

There are reports of several caves in Dinosaur NM. One cave has been explored to a distance of 1000 feet (300 m) but apparently it continues on. Access to another cave is deemed treacherous and at least one cave is known to contained archeological materials. One of the caves has been partially mapped in a cursory way.

In spite of these reports and the acknowledged large exposures of limestone rock in the monument, there has been no systematic search to locate and evaluate the number, distribution, and significance of caves in Dinosaur. Present knowledge of the caves in the monument is spotty and anecdotal. Dinosaur National Monument has asked for technical assistance to develop a cave management plan for known cave resources and develop funding requests for a comprehensive inventory of caves in the monument. The need for a cave inventory and assessment of paleontological resources was identified in the 2005 draft Paleontological Resource Review, Management and Research Plan, for Dinosaur National Monument.

Mineral Resources

Federal mineral leasing is prohibited within the boundaries of Dinosaur National Monument as is the location of new mining claims. Approximately 4,500 acres in the park are non- federally owned and could potentially be the subject of proposals to develop private mineral rights. If that occurred, the NPS would regulate that activity. However, no mineral production on this acreage is taking place at this time.

Coal

Coal is present in the vicinity of the park; however, there has been no federal coal leasing immediately adjacent to the park. In the late 1980's several Preference Right Leases for coal were issued in an area located over 10 miles south of the park, but information on the current status of these leases is unavailable.

Oil and Gas

Also in the late 1980's, Conoco Inc., drilled the "Blue Mountain Unit #1- A" exploratory oil and gas well on BLM lands directly adjacent to the Harpers Corner Road scenic easement. The well did not produce and was subsequently plugged and abandoned. More recently, the Bureau of Land Management has been actively engaged in issuing oil and gas leases on BLM administered lands immediately west of the Harpers Corner Road and also south of the Monument headquarters near Dinosaur, Colorado. After consulting with the NPS, BLM indefinitely deferred oil and gas leasing within ½ mile of the park headquarters and further agreed to a 1200 foot setback for leases adjacent to the Harpers Corner Road scenic easement. The BLM agreed to enforce a "Visual Resource Management Level 2" designation for this area. Numerous oil and gas wells have been drilled further west of the Harpers Corner Road in Utah, but are still in the viewshed of the park.

Oil Shale

The BLM is preparing to amend existing applicable Resource Management Plans to address oil shale and tar sands resources leasing in Wyoming, Colorado and Utah. Although tar sands do not occur in the vicinity of Dinosaur National Monument, the park is literally surrounded by oil shale basins. Oil shale leasing may occur to the northwest of Dinosaur in the Green River Basin (Wyoming), to the northeast in the Washakie Basin (Wyoming), to the southwest in the Uinta Basin (Utah), and to the Southeast in the Piceance Creek Basin (Colorado).

Potential Geologic Research

In addition to the need for a geologic hazards map, there is also a need for a hydrology and geomorphology study of Cub Creek, and a comprehensive geologic engineering study of the Morrison clays. The following research needs were discussed at the 1998 workshop:

- Association of rare plants with certain geologic strata
- Comprehensive, multidisciplinary study of the Cedar Mountain and correlative formations
- Storage facilities for paleontological specimens

Tamara Naumann, botanist at Dinosaur NM, noted the association of rare plants with certain geologic strata and geomorphic surfaces using the rare Ute Ladies- Tresses Orchid as an example. The rare orchids grow in Lodore Canyon and show a strong correlation with geomorphic surfaces formed under the flow regime established by discharge from Flaming Gorge dam. Increased flows from Flaming Gorge have been proposed to assist the endangered fish in the Green River. The affect of increased flow on the orchid population is unknown. In 1998, further research was needed to determine the effect of flooding on the existing surfaces and plants, as well as, how and if these flows might create new habitat for the orchid.

In recent years, dinosaur fossils have been found in the Lower Cretaceous Cedar Mountain Formation. A comprehensive, multidisciplinary study of the Cedar Mountain Formation and its correlative formations would help define the paleoenvironments of that time period. Research into the sedimentology, stratigraphy, palynology, pedology, invertebrate paleontology and paleobotany of the Cedar Mountain Formation would greatly enhance the understanding of the new quarry.

Although not discussed in the 1998 meeting, other issues of interest to Dinosaur staff include: a need for geological and paleontological studies of the Lower Cretaceous Dakota Sandstone, and the Upper Cretaceous Mowry Shale and Frontier Sandstone; geological studies of the Triassic Moenkopi Formation and of the Lower Jurassic Glen Canyon Formation; and an inventory of the Upper Jurassic Chinle Formation.

Fossil specimens are prepared in the Quarry Visitor Center. The ever- growing collection of fossils has put a strain on this storage facility. There have been a number of engineering studies of the structural problems discussed above, but the building continues to deteriorate. Plans are underway to either rehabilitee or rebuild all or part of the structure to provide the infrastructure for preparation, curation, research, resource management, and inventory and monitoring of the fossil collections. Other fossils are stored in sheds or the basement of the headquarters building more than 20 miles away. These storage facilities are improperly ventilated creating a hazard by the buildup of radon gas, a product of the radioactivity associated with many specimens.

Interpretive Needs

Specific interpretive issues were not discussed in detail at the workshop, but several resources associated with geology included:

- The Morrison Initiative: Christine Turner and Fred Peterson of the USGS worked on the Morrison Initiative. Their comprehensive report is complete and available to Dinosaur staff.
- Christine Turner and Fred Peterson also discussed the need for a geologic guidebook and road log linking Permian formations among various parks and other sites on the Colorado Plateau.
- Several interpretive publications related to the geology of Dinosaur NM are available in the monument bookstores and mentioned in the workshop scoping report (Appendix B).

Geologic Features and Processes

This section provides descriptions of the most prominent and distinctive geologic features and processes in Dinosaur National Monument.

Dinosaur Quarry

Preservation of the dinosaur quarry was the impetus for the creation of Dinosaur National Monument. The eight articulated tail vertebrae of *Apatosaurus* that Dr. Earl Douglas saw projecting from the Morrison ridge led to the discovery of the remains of over 400 individuals, making this quarry one of the greatest dinosaur localities ever found.

There are three layers of bones at Dinosaur NM. Bones in the first layer were generally extracted for museums and exhibits. The second layer is mostly what exposed at the quarry and cliffs at Dinosaur. The third layer has not been as fully developed as the others. The orientation of the bones as well as the sedimentology of the layers indicates that the dinosaurs were preserved in a fluvial environment. Much like bison carcasses that collected in the meanders of the Missouri and Platte Rivers during flooding season, dinosaurs were log- jammed in the rivers in Morrison time - either caught in floods or drowned in some other way. Sediment carried by the floods rapidly buried the bones, resulting in the excellent preservation seen today. The femurs, vertebrae, and other large limb bones are oriented parallel to flow and there is segregation of large bones from smaller digit bones. These smaller bones (like twigs) were transported farther down stream than the larger bones. This segregation of bone size can be seen in the quarry.

Some of the bones are very small, such as the ear bone that proved dinosaurs could actually hear (first found at Dinosaur NM). Yet some of them are in close approximation to larger bones, which may or may not have been from the same animal. The wear on some bones looks as though they traveled some distance while others appear fresh, as if the animals drowned and were buried on the spot. For more information on the history of Dinosaur Quarry and the paleontology of the monument please refer to the Paleontology section of Gregson and Chure (2000) and to the paleontology summary paper by Santucci (2000).

Canyons

Recognized as two of the great river gorges of western North America, the canyons of the Green and Yampa Rivers each possess their own unique character. The Canyon of Lodore, cut by the Green River, exposes red rocks of the Precambrian Uinta Mountain Group for most of its length. These reddish cliffs tower 600 m (2,000 ft) above the surface of the river. Exposures of Weber Sandstone dominate the precipitous walls of Yampa Canyon. One cliff, called the Grand Overhang by river runners, is 330 m (1,100 ft) high and exposes the entire thickness of the Weber. The cliff is an undercut, overhanging wall of sandstone located within the deeply entrenched gooseneck meanders of the Yampa River below Harding Hole (Hansen, 1996; Gregson and Chure, 2000).

Other unique and spectacular canyons include Split Mountain Canyon, Whirlpool Canyon, and Jones Hole. As the name implies, Split Mountain is split by the Green River, which has exposed a unique cross- sectional perspective of the Split Mountain anticline. As it flows through Split Mountain, the Green River drops an average of 3.7 m per km (19.5 ft per mi.), the steepest gradient of any other canyon in Dinosaur. The contact between the Uinta Mountain Group and the overlying Lodore Sandstone is exposed in Whirlpool Canyon, a canyon that the Green River has cut through the uplifted Mitten Park structural block, exposing the Mitten Park and Island Park faults as well. At this contact, are fossil sea stacks about 55 m (180 ft) high which were buried by the sediments of the Cambrian Lodore sea more than 500 Ma (Hansen, 1996).

Downstream lies Jones Hole, an extended, steep- walled canyon. Jones Creek emerges abruptly from openings in the Round Valley Limestone about 6.5 km (4 miles) above its confluence with the Green River in Whirlpool Canyon. Upper Jones Hole follows the Island Park fault trace from the Jones Creek springs down to its confluence with Ely Creek, a smaller tributary stream. The fault places Cambrian- age Lodore strata against Pennsylvanian- age rocks.

Weber Sandstone and Steamboat Rock

The Weber Sandstone almost always forms towering landforms where it is exposed. The best known of these is Steamboat Rock in Echo Park. This enormous sandstone monolith towers 320 m (1,050 ft) above the Green River and is more than a mile long (Hansen, 1996). Erosion by the Green River on the inner side of an entrenched meander formed Steamboat Rock and carved the outer canyon walls of Echo Park (Gregson and Chure, 2000). The Weber Sandstone also forms the hogbacks, flatirons, and box canyons that are a part of Split Mountain and the south side of Blue Mountain. Although exposed at the surface in the monument, the Weber Sandstone dips into the subsurface south of Blue Mountain outside of the monument. In the subsurface, the Weber Sandstone is the primary reservoir rocks of the giant Rangely Oil Field southeast of the monument.

Type Localities

A type locality is an area where exposed strata are first definitively described and documented by geologists. Two formations have their type localities within or near Dinosaur National Monument. The type locality of the Lodore Formation is located at the southern end of

Lodore Canyon near Limestone Draw. This site is about 4 km (2.5 mi) upstream from Echo Park and the confluence of the Green and Yampa Rivers. Major John Wesley Powell first named the formation as the Lodore Group in 1876. The Browns Park Formation has its type locality in Browns Park, Colorado and Utah. In 1876 John Wesley Powell also was the first to use the name Browns Park Formation.

Laramide Structures

"The Dinosaur area contains some of the best exposures of Laramide- age faults and folds found anywhere within the Rocky Mountains," (Gregson and Chure, 2000). Exposures of Laramide- age structures range from high-angle normal faults to classic low- angle thrust faults. Fold shapes range from classic cylindrical to quite angular and kink- like folds. Thrust faults are exposed at Hells Canyon and Mitten Park. Cylindrically- folded strata at Mitten Park become tight, kink- like folds just a few miles south at the Ruple Point- Red Rock anticline. Analysis of structures in Dinosaur NM has supported a variety of tectonic theories and models through the years. See Gregson and Chure (2000) for a list of references.

Geologic Association with Pikeminnow

The spawning sites of the Colorado Pikeminnow (formerly called squawfish) in the Lower Yampa Canyon appear to be associated with geologic structure and lithology. The bedrock- incised channel bottom of the Lower Yampa has formed in response to downstream folding. The pikeminnow spawn on bank- attached and mid- channel bars at three locations in the canyon, which is located on the east- dipping flank of a northeast-trending anticline. Furthermore, the contact between the Weber Sandstone and the limestone of the underlying Morgan Formation are the discharge sites of carbonate – rich seeps and springs. Water conductivity is higher where these spawning bars are located (Mussetter and Harvey, 1999).

Map Unit Properties

This section provides a description for and identifies many characteristics of the map units that appear on the digital geologic map of Dinosaur National Monument. The table is highly generalized and is provided for informational purposes only. Ground disturbing activities should not be permitted or denied on the basis of information contained in this table. More detailed unit descriptions can be found in the help files that accompany the digital geologic map or by contacting the NPS Geologic Resources Division.

This section explains specific properties associated with the geologic formations that have been identified and mapped in the park. The properties of specific units may be informative when making management decisions. Geologic features and processes are often specific to a particular stratigraphic unit (group, formation, or member).

Dinosaur NM offers one of the most complete stratigraphic columns exposed within the National Park System (Untermann and Untermann, 1969; Hansen, 1977; Gregson and Chure, 2000). Except for the Ordovician, Silurian, and Devonian, all of the geologic periods (figure 3) are represented in the Dinosaur NM area. Almost all of the rocks exposed in the area are sedimentary and range in age from Precambrian (about 1,100 Ma) to Miocene (about 25 to 10 Ma) (Hansen and others, 1983; Hansen, 1986a, 1986b; Gregson and Chure, 2000). The Quaternary Period is represented by unconsolidated alluvium.

Precambrian strata are exposed in the northern part of the monument, in the Lodore Canyon area. Upper Paleozoic strata form the core of the Split Mountain and Red Rock anticlines. Mesozoic rocks flank these anticlines.

The following Map Unit Properties Table identifies properties specific to each unit present in the stratigraphic column including: map symbol, name, description, topographic expression, resistance to erosion, suitability for development, hazards, potential paleontologic resources, mineral resources, and global significance.

Map Unit Properties Table

Age	Unit Name (Symbol)	Lithology and Description	Topographic Expression	Erosion Resistance	Suitability for Development	Hazard Potential	Potential Paleontologic Resources	Mineral Specimens & Resources	Global Significance
Quaternary	Unconsolidated material (Q)	Highly variable; includes alluvial, landslide, terrace and gravel deposits, eolian sand, talus, and debris fan deposits; variable thickness	Variable	Low	Variable	Debris flow and flooding potential	Quaternary (Holocene) flora	None	None
Major Regional Unconformity									
Tertiary	Browns Park Formation (Tbp)	Variable; primarily sandstones and unconsolidated tuffs with minor chert, limestone, siltstone, conglomerate, and mudstone; 600 ft (490 m) thick	Forms Browns Valley north of Gates of Ladore	Variable	Some lake clay and volcanic deposits; some floodplain	Low	Lake clays: ostracods and diatoms	Unknown	Type locality in Browns Park
	Bishop Conglomerate (Tb)	Light gray to pinkish- gray to tan, poorly sorted, loosely cemented, pebble, cobble, boulder conglomerate and coarse- grained sandstone; 200- 500 ft (60- 150 m) thick to very thin due to post- Bishop erosion	Local outcrops on Blue Mountain, Yampa Plateau, Ruple Ridge, trail to Harpers Corner, near Jones Hole, and drainages of Diamond Gulch and Pot Creek	Loosely cemented	Isolated deposits; probably not an issue with regards to development	Low	None documented	Unknown	None
Major Regional Unconformity									
Upper Cretaceous	Mesaverde Group (Kmv)	Transitional from marine and near- shore sandstone and shale to lagoon, swamp, and continental sandstone with coal in upper part: 2600 ft (800 m) thick	Ridge former; Not exposed in Dinosaur	Variable	Not exposed in Dinosaur	Not exposed in Dinosaur	Not exposed in Dinosaur	Coal elsewhere	None
	Sego Sandstone (Kmvs)	Gray marine shale with fossiliferous (Baculites) dolomite concretions; 0- 250 ft (0- 75 m) thick	Ridge former; Not exposed in Dinosaur	Moderate	Not exposed in Dinosaur	Not exposed in Dinosaur	Not exposed in Dinosaur	Not exposed in Dinosaur	None
	Buck Tongue, Mancos Shale (Kmb)	Thickness: 200- 500 ft (60- 150 m)	Slope former; Not exposed in Dinosaur	Low	Not exposed in Dinosaur	Not exposed in Dinosaur	Not exposed in Dinosaur	Not exposed in Dinosaur	None
	Castlegate Sandstone (Kc)	Gray marine shale with fossiliferous (Baculites) dolomite concretions; thickness: 0- 100 ft (0- 30 m)	Ridge former; not exposed in Dinosaur	Moderate	Not exposed in Dinosaur	Not exposed in Dinosaur	Not exposed in Dinosaur	Not exposed in Dinosaur	None
	Mancos Shale (Km)	Dark gray, silty to clayey, marine shale that weathers light gray to light yellow; minor siltstone and sandstone in upper part with layered bentonite and a few limestone beds in the lower part; locally fossiliferous; thickness : 4800- 5600 ft (1450- 1700 m)	Slope and valley former	Low: landslide potential; cutbank erosion along streams and rivers	Bentonite clay may cause problems	Slippery when wet; Swelling clay	Invertebrate marine fauna: mollusks (*Inoceramus*), ammonites (*Baculites*), brachiopods, bryozoans, trace fossils	Gypsum	None
	Frontier Sandstone (Kmf)	Upper part: light- brown to light- greenish- gray, thin- bedded to massive, fine- grained calcareous sandstone; locally cross- bedded with ripple marks; Lower part: dark- gray, fossiliferous, calcareous shale, silty shale, and siltstone; 100- 300 ft (30- 90 m) thick	Upper part: hogbacks & flatirons; Lower unit: slopes & saddles	Upper part: resistant to erosion; Lower part: low resistance	Development on hogbacks will impact viewscape	Potential rockfall	Invertebrate marine fauna in lower part: bivalves, ammonites, gastropods & petrified wood	Coal in upper part; hydrocarbons elsewhere	None
	Mowry Shale (Kmm)	Hard, gray, fissile, siliceous shale; 33- 220 ft (10- 65 m) thick	Forms narrow strike valley between Dakota Sandstone and Frontier Sandstone	Low: forms valleys	Bentonitic soils	Slippery when wet	Fish scales, shark teeth	Bentonite	None
Lower Cretaceous	Dakota Sandstone (Kd)	Light- gray to yellow, cross- bedded, medium- to coarse- grained to pebbly sandstone and minor pebble conglomerate with subordinate black carbonaceous shale; 40- 100 ft (12- 30 m) thick	Forms hogbacks	Highly resistant	Development on hogbacks will impact viewscape	Potential rockfall	Petrified wood & invertebrate shell fragments	Hydrocarbons elsewhere	None
	Cedar Mountain Formation (Kcm)	Colorful clay- and siltstone, some sandstone; local conglomerate (Buckhorn Conglomerate); 0- 200 ft (0- 60 m) thick	Erodes with Morrison to form strike valleys & low ridges	Mudstone & siltstone have a lower resistance than sandstones	Similar to Morrison Fm.	Similar to Morrison Fm.	Sauropod skull, deinonychid (*Utahraptor*), and small mammals	Possible uranium	Sauropod skull is one of the most important Cretaceous fossils found to date

Age	Unit Name (Symbol)	Lithology and Description	Topographic Expression	Erosion Resistance	Suitability for Development	Hazard Potential	Potential Paleontologic Resources	Mineral Specimens & Resources	Global Significance
Jurassic	Morrison Formation (Jm)	Multi- colored mudstone and siltstone, with bentonite, sandstone, and conglomerate; dinosaur fossils; 650- 1000 ft (200- 300 m) thick	Mudstones form slopes; sandstones tilted into hogbacks	Mudstones have a low resistance & landslide potential; sandstones are more resistant to erosion	Shifting substrate; bentonite in mudstone	Mudstones are slippery when wet due to bentonite; radon gas	Dinosaurs, e.g. *Stegosaurus*, *Camarasaurus* *Ornitholestes*, *Diplodocus*, *Apatosaurus*, *Allosaurus*, *Barosaurus*, *Camptosaurus*; also turtles	Major source of uranium ore minerals	World renown dinosaur fossils including relatively complete skeletons and skulls
	Stump Formation (Js)	Redwater mbr: light- green to olive- green, fissile, glauconitic siltstone and shape with sparse interbeds of tan, lavender, or greenish- gray cross- bedded, glauconitic, oolitic, fossiliferous limestone and sandstone; thins from about 130 ft (40 m) in the western part to 70 to 90 ft (22- 27 m) in the east. Curtis mbr: light- gray to light- greenish- gray, thin- to medium- bedded, cross- bedded, medium- to coarse- grained sandstone; ripple marks locally and fossiliferous; thins from about 50- 100 ft (15- 30 m) in western Dinosaur to about 23 ft (7 m) at Deerlodge Park	Redwater mbr: forms slopes; Curtis mbr: forms ledges	Redwater mbr: softer, less resistant to erosion. Curtis mbr: more resistsnt	None documented	Low	Redwater mbr: brachiopods, bivalves, echinoderms, cephalopods (belemnites). Curtis mbr: sparse bivalves, traces of bottom dwellers	None	None
	Entrada Sandstone (Je)	Pink to yellow- gray, fine- to medium- grained quartz sandstone with eolian cross- bedding; thins eastward from 165 ft (50 m) at Dinosaur Quarry to 40 ft (12 m) at Deerlodge Park	Cliff former but outcrops are more subdued than Glen Canyon Sandstone	High	Development on Entrada will impact viewscape	Rockfall	Not fossiliferous in Dinosaur	None	Evidence of vast sand dunes
	Carmel Formation (Jca)	Dark- red sandy siltstone and mudstone; thickens westward and pinches out toward the east, ranging from about 130 ft (40 m) thick near Island Park, about 110 ft (33 m) south of Cub Creek, to about 60 ft (19 m) at Plug Hat Rock	Forms a narrow ribbon of subdued, easily eroded red rocks and strike valleys	Low	None documented	Low	Marine fossils: clams (*Arctica*)	Gypsum crystals	None
	Glen Canyon Sandstone (Navajo/Nugget equivalent (JTRg)	Pink to gray- yellow eolian cross- bedded quartz sandstone; thickness 600- 650 ft (180- 200 m)	Strike ridges, hogbacks, cuestas flanking Split Mt. & Blue Mt.	High	Development on hogbacks will impact viewscape	Rockfall	None	None	Evidence of vast eolian sand dunes in extensive sand sea (erg)
Triassic	Chinle Formation (TRc)	Red to gray siltstone, sandstone, and shale with local basal conglomerate (Gartra member); 200- 460 ft (60- 140 m) thick	Garta mbr. forms cliffs, benches, caprocks, hogbacks; main body of Chinle forms slopes and narrow strike valleys	Low: erodes easily except for Garta member	Unknown	Low	Vertebrates, e.g. *Phytosaur* (crocodile relative), teeth, bone fragments, wood	Potential uranium resources; petrified wood	None
	Moenkopi Formation (TRm)	Mostly red to brown, green, and gray siltstone and shale and fine- grained sandstone; gypsiferous siltstone and shale near base; ripple marks; thickness: 500- 800 ft (150- 240 m)	Forms floor of many strike valleys and colorful flatirons at Split Mt. gorge	Low	Unknown	Low	Sparse; mollusks some reptile tracks (e.g., *Chirotherium*);	Gypsum	None
Major Regional Unconformity									
Permian	Park City Formation (Pp)	Phosphatic marine sandstone, siltstone, dolomite, and limestone with fossils; 100- 430 ft (30- 130 m) thick	Green and yellow flatirons; forms protective cap on Weber	Resistant lower ss and cherty limestone; Upper shale, siltstone, limestone, and sandstone more easily eroded	Development on flatirons will impact viewscape	Rockfall	Marine invertebrates: pelecypods, scaphopods, gastropods, fusulinids, corals.	Phosphate	None
	Weber Sandstone (Pw)	Light gray to yellow- gray sandstone with sweeping eolian cross- beds; locally interlayered limestone beds; 650- 1500 ft (200- 470 m) thick.	Monoliths and cliffs, most notable landforms	High with well- cemented quartz sandstone	Development on Weber will impact viewscape	Rockfall		Hydro- carbon reservoir	Exposes classic Laramide structures
Pennsylvanian	Morgan Formation (PNm)	Upper: Red fine- grained sandstone with gray to pale lavender, cherty, fossiliferous marine limestone; thickness 500- 575 ft (150- 175 m) Lower: light- gray to red and green shale and siltstone; 130- 300 ft (40- 90 m) thick	Upper: forms red cliffs Lower: forms gray slopes	Upper part is resistant; Lower part is easily eroded	Exposures in Yampa Canyon, Lodore Canyon, and Split Mountain anticline are unsuitable for development	Rockfall in upper part; upper part may be undercut by eroding lower part leading to cliff collapse	Marine invertebrates: abundant brachiopods, bryozoans, sponges, algae, foraminifera	None	None

Age	Unit Name (Symbol)	Lithology and Description	Topographic Expression	Erosion Resistance	Suitability for Development	Hazard Potential	Potential Paleontologic Resources	Mineral Specimens & Resources	Global Significance
Pennsylvanian	Round Valley Limestone (PNrv)	Light gray to pale lavender, thick- bedded limestone, with thin partings of gray to red shale; pink to red chert; fossiliferous; 200- 300 ft (65- 90 m) thick at Split Mt. and 400 ft (120 m) at the head of Yampa Canyon	Forms gray ledgy slopes and/or multi- tiered cliffs	High	Topographic position makes this formation unsuitable for development	Rockfall and ledge collapse		Chert nodules	None
Mississippian	Doughnut Shale/Humbug Formation (Mdh)	<u>Humbug</u>: light- gray to red, fine- to very fine grained sandstone interbedded with light- gray limestone and red to black shale. <u>Doughnut</u>: gray shale and gray to red sandstone. Combined thickness: 250- 300 ft (75- 90 m)	<u>Humbug</u>: forms ledgy slopes <u>Doughnut</u>: forms slopes	Humbug Fm is relatively high; Doughnut Shale is relatively low	Doughnut Shale contains bentonite	Doughnut Shale becomes plastic when wet and prone to landslides	Fish and marine invertebrates: crinoids, trilobites, gastropods, cephalopods, corals, echinoderms	Traces of coal	None
	Madison Limestone (Leadville equivalent) (Mm)	Light- to dark- gray, thick and unevenly bedded, cherty limestone and dolomitic limestone, sparsely fossiliferous; 600- 680 ft (180- 200 m) thick	Jagged cliffs and dip slopes	High	Dip slopes pose potential development problems	Karst (sinkhole) potential		None	Part of interior sea from present day Arctic Ocean to the Gulf of Mexico
Major Regional Unconformity									
Cambrian	Lodore Formation (Cl)	Light brown to green sandstone and shale with basal coarse to pebbly transgressive marine sandstone; thickness: 230- 600 ft (70- 180 m)	Ledge- forming sandstone; slope- forming shale	Variable	Low	Rockfall and cliff collapse	Rare trilobite body parts, trace fossils	Glauconite occurrence	Type locality is near Limestone Draw in the lower reach of Lodore Canyon
Major Regional Unconformity									
Precambrian	Uinta Mountain Group (Yu)	Red fine- to coarse- grained, pebbly, quartzitic sandstone with occasional conglomerate; gray to green and red micaceous shale and siltstone. Thickness: 7000 ft (2100 m), bottom of formation is not exposed; up to 2400 ft (7000 m) thick in adjacent areas	Prominent outcrops and cliffs in Canyon of Lodore	High	Low	Rockfall and cliff collapse	Fossilized algal globules found north of Dinosaur	None documented	Deposited about 1.1 billion years ago

Geologic History

This section highlights the map units (i.e., rocks and unconsolidated deposits) that occur in Dinosaur National Monument and puts them in a geologic context in terms of the environment in which they were deposited and the timing of geologic events that created the present landscape.

Precambrian

Continents evolve through a process called accretion wherein materials are added to a central continental core, known as a craton. By this process a continent grows in areal extent through time. Continents may also merge and later fragment, resulting in complex histories to unravel.

About 2.5 billion years ago (Archean Eon) in the Precambrian, the area that is now Wyoming formed the southern margin of the North American craton. Sedimentary rocks were deposited and later metamorphosed in a broad continental shelf that extended to the south and west. As Archean time drew to a close, the North American craton experienced a growth spurt. Studies of folds and faults in the Red Creek Quartzite beneath the overlying Uinta Mountain Group indicate that a collisional event began to affect the area about 2.3 billion years ago (figure 4) (Hanson, 1975).

About 1.5 billion years ago a broad, elongate east- west trough formed along the southern edge of the Wyoming area and filled with the sediments of the Uinta Mountain Group, now exposed in Uinta Mountains and in Dinosaur National Monument. The trough was probably a failed arm of a rifted continental margin (an aulacogen) (Gregson and Chure, 2000). Ripple marks, fossil mud cracks, and even rain prints suggest that sedimentation kept pace with subsidence and that the basin was not very deep (Hanson, 1975). Sediments thousands of feet thick were deposited, lithified, and then uplifted, tilted northeastward, and partially eroded forming the Unita Mountian Group (Hansen, 1986b; Gregson and Chure, 2000). This period of erosion with little or no sedimentation created a hiatus (gap) in the stratigraphic record that lasted several hundred million years until Late Cambrian. The nature of this unconformity is described in Hanson (1977).

Paleozoic Era

Rare body fossils of trilobites have been found in the Cambrian Lodore Formation at Jones Hole (Hanson, 1996). Sediments and body fossils suggest that the Lodore environment was one of warm, shallow marine water.

Another break in sedimentation from the Late Cambrian to the Early Mississippian indicates the area must have remained relatively high for several million years from the Ordovician Period through the Devonian Period. While the western margin of North America was experiencing accretionary tectonic activity from the Antler Orogeny, extensive shallow seas repeatedly transgressed and regressed across the Dinosaur area depositing the Lower Mississippian Madison Limestone, the sandstone, limestone, and shale of the Upper Mississippian Humbug Formation, and the dark- gray Doughnut Shale. During the Early Mississippian, a shallow sea reached from the present day Arctic Ocean to the Gulf of Mexico (figure 5).

Coal in the Doughnut Shale suggests brief intervals of non- marine conditions during the Upper Mississippian. Fresh or brackish water in vegetation- rich swamps mixed with marine environments that led to the deposition of coal (Gregson and Chure, 2000).

Marine environments returned with deposition of the Round Valley Limestone of the Lower Pennsylvanian. The Round Valley Limestone marks a change in tectonic regime. Intermixed with the limestone are nodules of pink and red chert. The chert marks the initiation of a tectonic event that formed the Ancestral Rocky Mountains in Colorado (figure 6).

Although deformation related to the Pennsylvanian- Permian Ancestral Rocky Mountain Orogeny has not been recognized in the Dinosaur area, the sedimentation rates of the late Paleozoic and Mesozoic were greatly affected by plate tectonic activity that was suturing South America onto the North American continent. Hundreds of feet of Middle Pennsylvanian Morgan Formation were deposited in beach and near- shore shallow marine environments that developed in the Uinta trough. Overlying the Morgan Formation is upwards of 470 m (1,500 ft) of Middle Pennsylvanian to Lower Permian Weber Sandstone. The sweeping cross- beds in the Weber indicate that most of the formation was deposited in a beach and sand dune environment. Local interlayered limestone beds containing marine fossils show a close marine association (Gregson and Chure, 2000).

A marine environment once again returned to the area and is recorded in the Lower Permian Park City Formation. Deposits of phosphate- rich sediment accumulated as cold, mineral- rich, marine waters welled up from the bottom into warmer zones or currents. These deposits are now mined for fertilizer in the Brush Creek area northwest of Dinosaur NM (Hansen and others, 1980, 1983; Maughan, 1979; Rowley, Dyni, and others, 1979; Rowley, Kinney, and others, 1979; Rowley and others, 1985).

Mesozoic Era

The Lower Triassic Moenkopi Formation rests unconformably above the Paleozoic strata. Continental environments became more widespread during the Mesozoic and dominated the landscape. Near- shore continental (possibly tidal flat) environments formed the distinctive Moenkopi red beds. Gypsum precipitated in times of high aridity. The basal Garta member of the Upper Triassic Chinle Formation was deposited in streams and rivers possibly in paleovalleys cut into the underlying Moenkopi Formation (figure 7). The red to gray siltstone, sandstone, and shale that makes up the main body of the Chinle represent channel, flood plain and lake deposits.

Eolian environments are recorded in the Lower Jurassic Glen Canyon Sandstone and the Middle Jurassic Entrada Sandstone. The Glen Canyon Sandstone records an extensive sand sea (erg) that covered Utah, Wyoming, Colorado, and parts of Arizona and New Mexico. Between the Glen Canyon and Entrada Sandstones are shallow marine sandy shale, siltstone, sandstone, and evaporite deposits of the Middle Jurassic Carmel Formation. This formation records the encroachment from the north of a shallow sea into the southern Wyoming and northern Utah area. Consequently, the Entrada erg that formed following retreat of the shallow sea, was not as widespread as the Glen Canyon erg.

Plate activity increased at the end of the Middle Jurassic resulting in a major transgression of an inland sea that destroyed the vast ergs that once covered the Colorado Plateau (Kocurek and Dott, 1983). Marine deposits of the Stump Formation record this transgressive event.

The fluvial and overbank deposits of the Upper Jurassic Morrison Formation and the Lower Cretaceous Cedar Mountain Formation subsequently buried the Stump Formation during a regressive episode. Morrison environments were quite varied with sediments deposited in mudflats, overbank floodplains, stream channels, small eolian sand fields, and scattered lakes and ponds (figure 8) (Peterson, 1994). Dinosaur fossils at the Dinosaur NM quarry are found in a fluvial depositional system within the Salt Wash member of the Morrison. Bentonite in the Brushy Basin member of the Morrison records volcanic ash falls generated from distant volcanoes to the west. Dinosaurs roamed the Morrison environments that recent work documents as more arid with ephemeral streams than previously thought (Turner and Peterson, 1998).

By Cretaceous time, marine and marginal marine environments dominated the area. Crustal loading of the east- directed thrust sheets of the Sevier Orogenic thrust belt (west of Dinosaur) probably extended the entire length of North America creating a continental scale foreland basin during the Cretaceous. As the mountains rose in the west and the roughly north- south trending Western Interior Basin expanded, the Gulf of Mexico separating North and South America continued to rift open in the south, and marine water advanced northward into the basin. At the same time, marine water advanced southward onto the continent from the Arctic region. As the sea transgressed, shore and near- shore sediments accumulated forming the Dakota Sandstone, Mowry Shale, and Frontier Sandstone.

The seas advanced and retreated many times during the Cretaceous until the most extensive interior seaway ever recorded drowned much of western North America (figure 9). The Western Interior Seaway was an elongate basin that extended from today's Gulf of Mexico to the Arctic Ocean, a distance of about 4827 km (3,000 mi) (Kauffman, 1977). The western margin of the seaway coincided with the active Cretaceous Sevier Orogenic belt, but the eastern margin was part of a low- lying, stable platform ramp in Nebraska and Kansas. The marine Mancos Shale and its equivalent to the east, the Pierre Shale, were deposited in this sea. Eventually, as the western highlands encroached on the western margin of the sea, sedimentation increased and multiple cycles of coastal bar, beach, lagoon, and swamp deposits prograded eastward, filling the seaway. These sediments became the formations found in the Mesaverde Group and equivalents.

Cretaceous-Tertiary Laramide Orogeny

In the Late Cretaceous, basement structures began forming in the western foreland basin. These structures are the initial structural response to the Laramide Orogeny, and as they grew into uplifts and sub- basins, the last great seaway of the western interior regressed from the continent. The Laramide Orogeny evolved into a complex set of thrusted uplifts (highlands) and basins. Many of these uplifts, such as the Uinta, Wind River, and Sawatch, grew into immense mountain ranges, while others formed ridges within the intermontane basins, i.e., Douglas Creek, Rock Springs, and Moxa arches.

The relationship between Laramide deformation and thrusting in the Sevier- Wyoming thrust belt to the west is not well understood. The Uinta uplift, however, overlapped both the Sevier and Laramide events in space as well as time so that both events must have influenced its development (Gregson and Chure, 200, and references therein). With contraction, "the old rift basin inverted the subsided structure and uplifted the Uinta Mountain Group and underlying Precambrian rocks well above much younger strata in the surrounding basins," (Gregson and Chure, 2000, p. 174). Existing structures in the foreland were reactivated by Laramide compression that also generated multiple new structures.

Cenozoic Era

Erosion and sedimentation began almost simultaneously as Laramide foreland uplifts became positive features of the landscape. Most of the Laramide structures have long and complex histories. The Uinta uplift separated the greater Green River basin to the north from the Uinta Basin to the south. Large lakes filled these basins during the Eocene Epoch of the Tertiary Period. Lake Gosiute formed north of the arch and Lake Uinta formed to the south. The coarse boulders and gravel deposited near the mountain front became the Fort Union and Wasatch Formations. The finer sand and silt that traveled farther out into the basins became the Wasatch and Green River Formations. Fine calcareous and organic- rich muds accumulated as thick lakebed deposits and eventually became the marlstone and oil shale of the Green River Formation. None of these strata, however, are exposed in the Dinosaur area.

Laramide deformation had ceased by Oligocene time. Streams had leveled the uplands and mantled the area with gravel derived from the crest of the Uinta Range. The Bishop Conglomerate (about 29 Ma) blanketed an extensive pediment surface known as the Gilbert Peak erosion surface. The conglomerate extended up all the major valleys and filled in around the high peaks and ridges of the Uinta Mountains (Gregson and Chure, 2000; Hansen and others, 1980, 1983; Hansen, 1986a; Rowley, Dyni, and others, 1979; Rowley and others, 1985). Following the tectonic quiescence of the Oligocene, deformation resulted in subsidence and a north down, south up rotation of the Uinta range and the formation of the Browns Park basin in the Miocene.

After the Bishop Conglomerate was deposited, the Green and Yampa River drainages developed and evolved steadily during and after deposition of the Browns Park Formation (Gregson and Chure, 2000; Hansen, 1986a). The ancestral Yampa River flowed into the easternmost Dinosaur area and is responsible for the basal conglomerate of the Browns Park Formation. The ancestral Green River flowed eastward across the Rock Springs uplift in Wyoming. In middle Pleistocene, the Green River was captured by the present river drainage system. The re- entrenchment of the Green River continued after initial canyon development due to regional uplift and changes in river discharge. This entrenchment of the Green and Yampa Rivers is responsible for the spectacular canyons that dominate the landscape today. For more detailed information about Dinosaur's Neogene historical geology, please refer to Hansen (1986a).

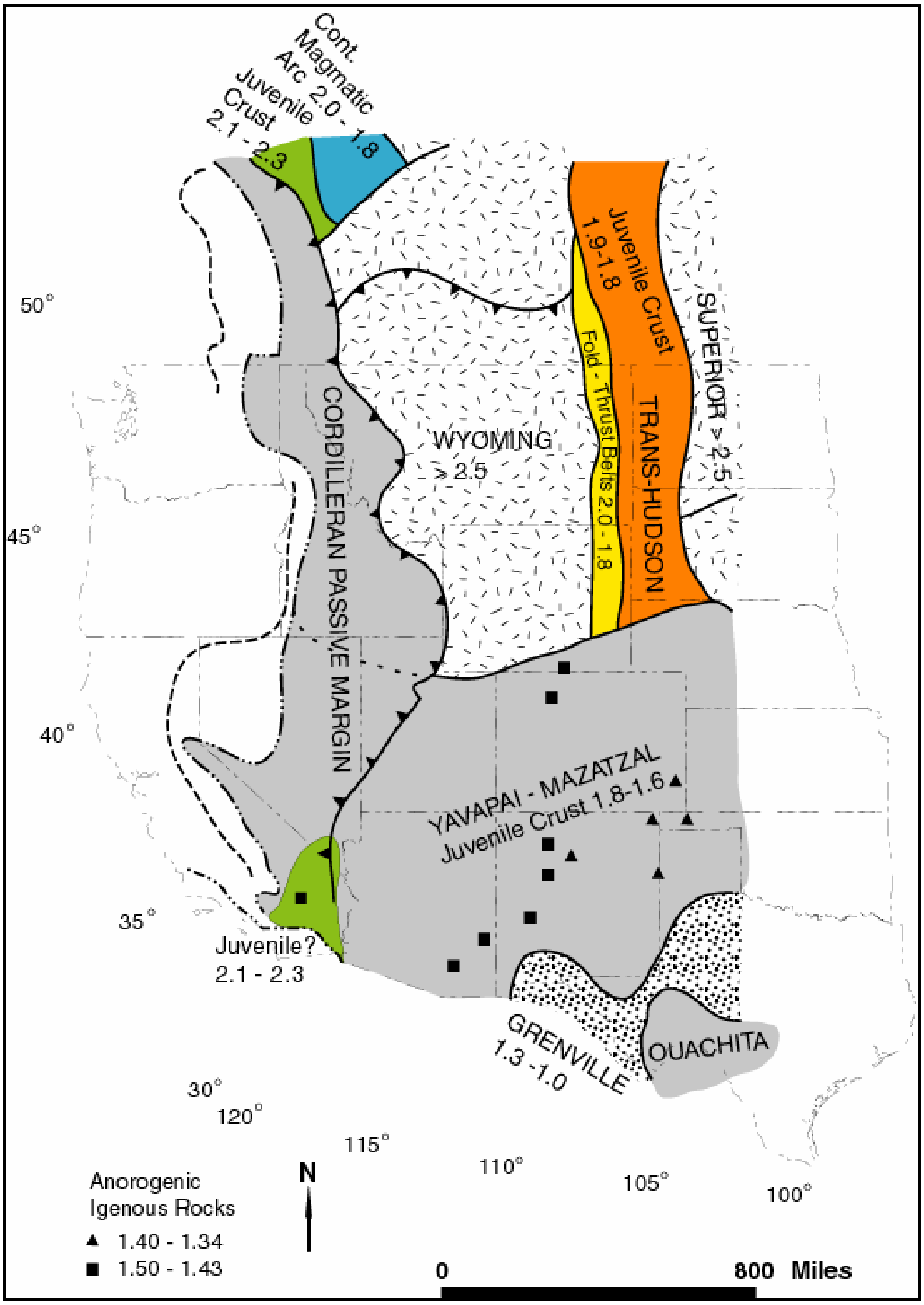

Figure 4. Precambrian orogenic belts that formed the western part of the North American craton. Ages are in billions of years. Thrust faults that sutured the landmasses together are marked by solid triangles with the triangles on the overthrust block of rock. The eastern limit of the north-south trending, Mesozoic Sevier thrust belt generally follows the eastern boundary of the Paleozoic passive margin and is shown here for reference (westernmost thrust trace). The North American crystalline basement is generally thought to extend to the Strontium isotope 0.706 or 0.704 line (dashed line). West of this line, oceanic crust prevails. Modified from Burchfiel and others, 1992.

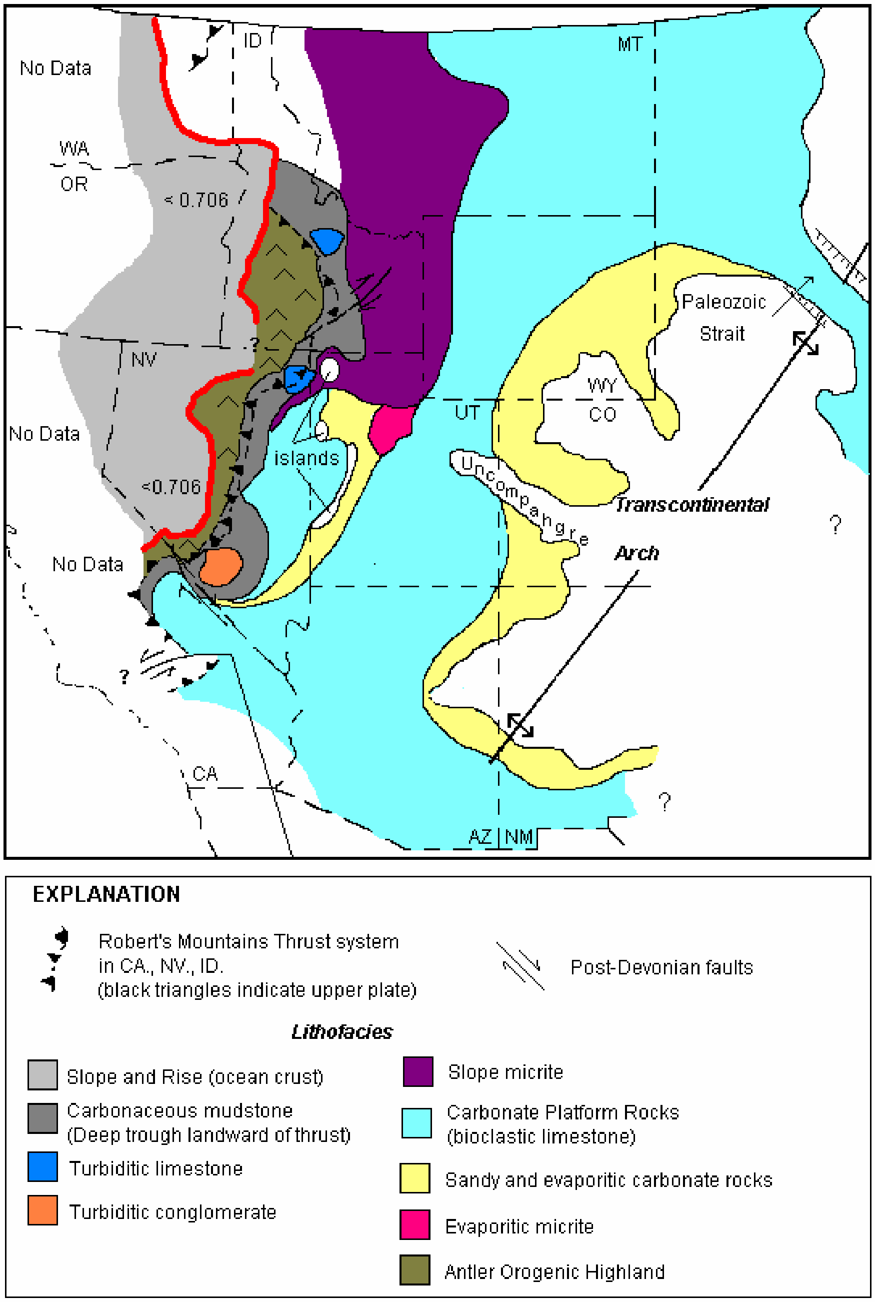

Figure 5. Paleogeographic map of the Early Mississippian Period of the western United States. While the lithofacies are complex in the foreland basin adjacent to the Antler orogenic highland, a broad carbonate platform spread over eastern Utah, depositing the Madison Limestone. Marine water also breached the Transcontinental Arch through the Paleozoic Strait. Any Mississippian rocks that were deposited on the transcontinental Arch or ancestral Uncompahgre highland during this time have been eroded. Modified from Poole and Sandberg, 1991.

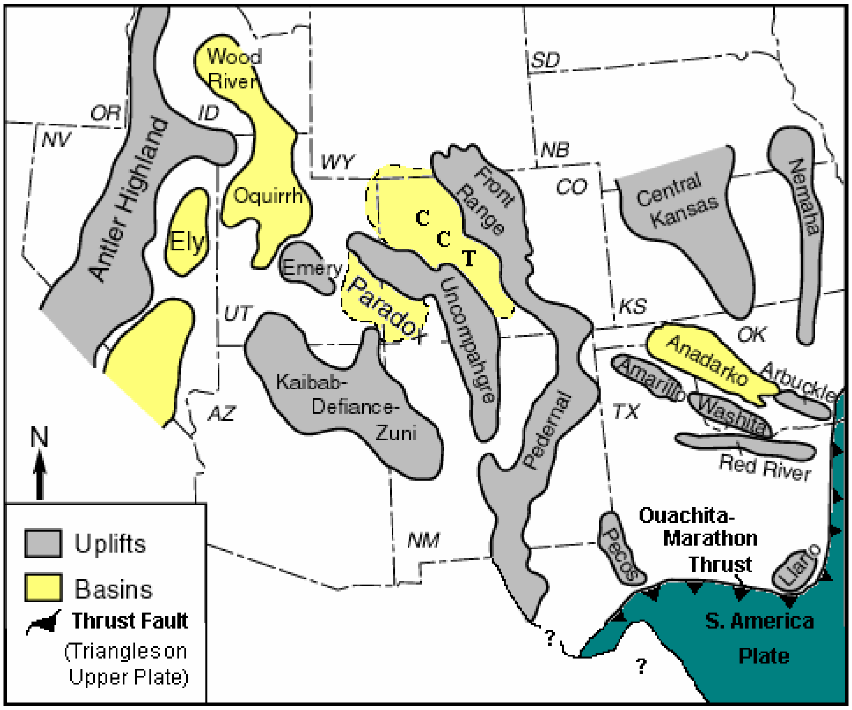

Figure 6. Major uplifts and basins present during the Pennsylvanian Period in the southwestern United States. Sediment eroded from the uplifts (gray) was deposited in the adjacent basins (yellow). Both the uplifts and basins resulted from compressional tectonics. Note the position of the South American Plate overriding the North American Plate. CCT: Central Colorado Trough. The trough formed between the Front Range and Uncompahgre Uplifts. Modified from Rigby, 1977.

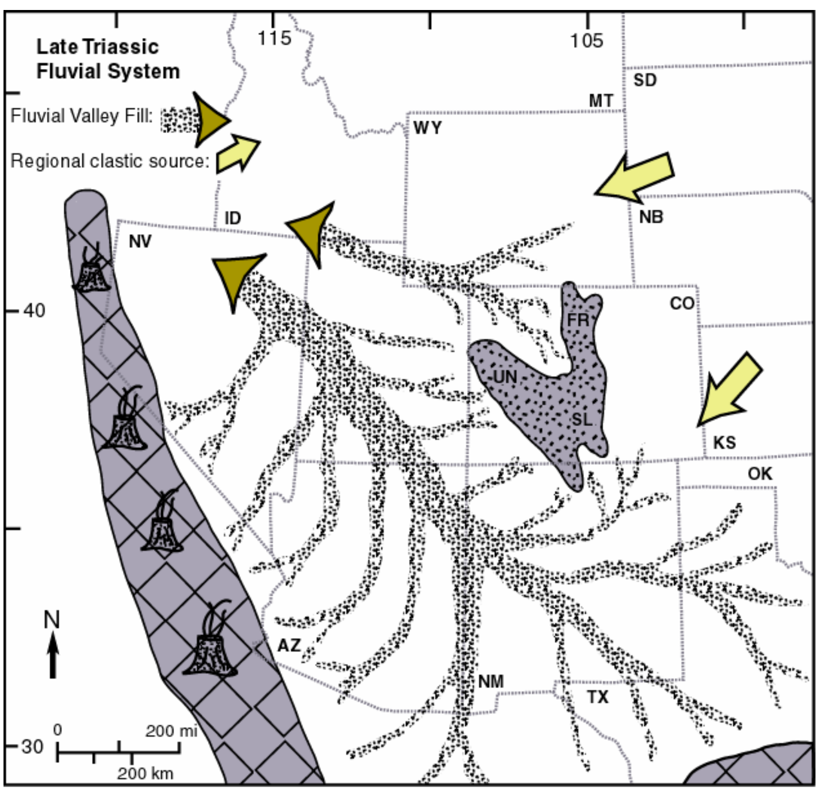

Figure 7. Paleogeographic map of the Late Triassic. UN: Uncompahgre uplift; SL: San Luis uplift; FR: Front Range uplift. Highlands are shaded a solid gray. Modified from Dubiel, 1994.

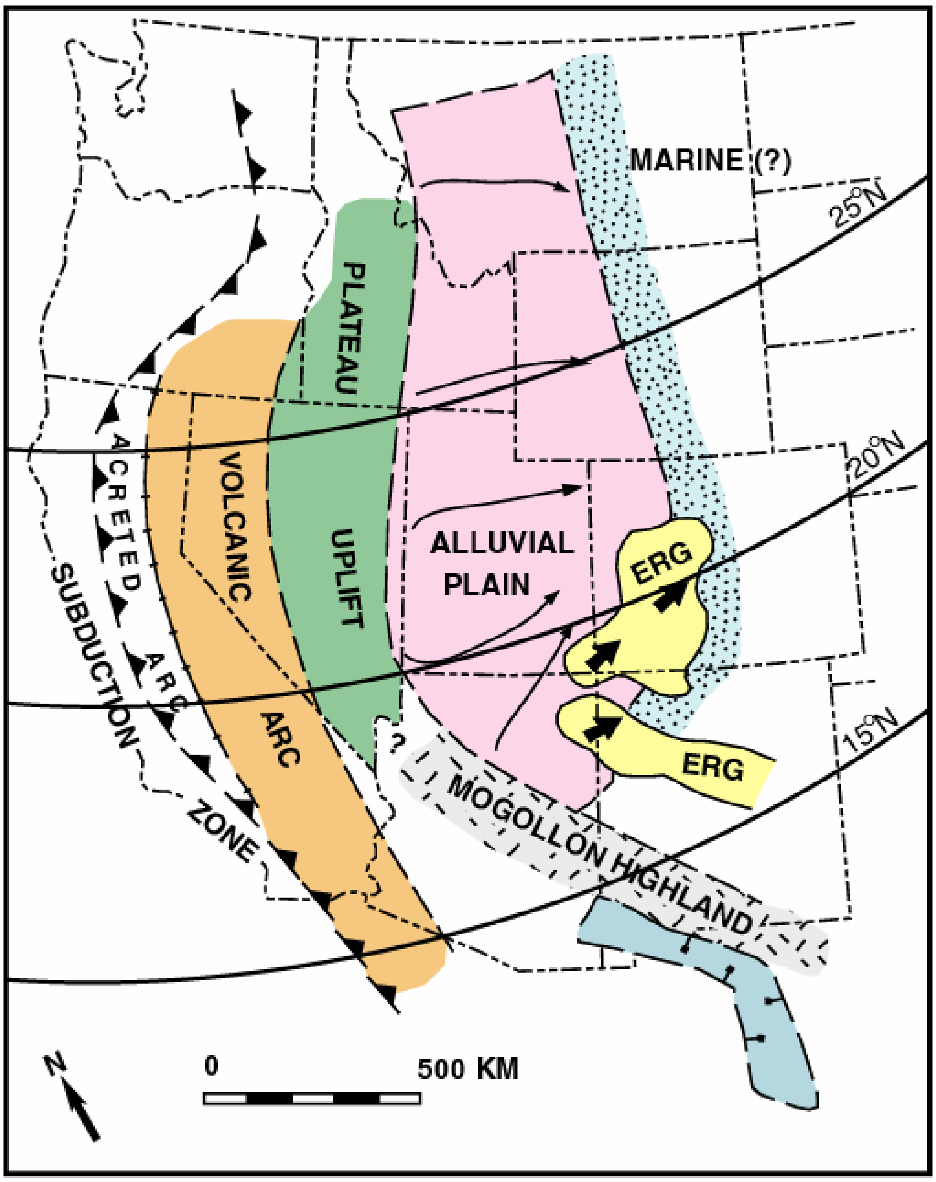

Figure 8. Late Jurassic paleogeography. Thin arrows indicate fluvial dispersal. Thick arrows indicate wind directions. Solid triangles indicate the location of the subduction zone with the triangles on the overriding, upper lithospheric plate. Note the possible marine environment to the east where continental environments were previously established. The alluvial plain expanded to the east with time. Modified from Lawton, 1994.

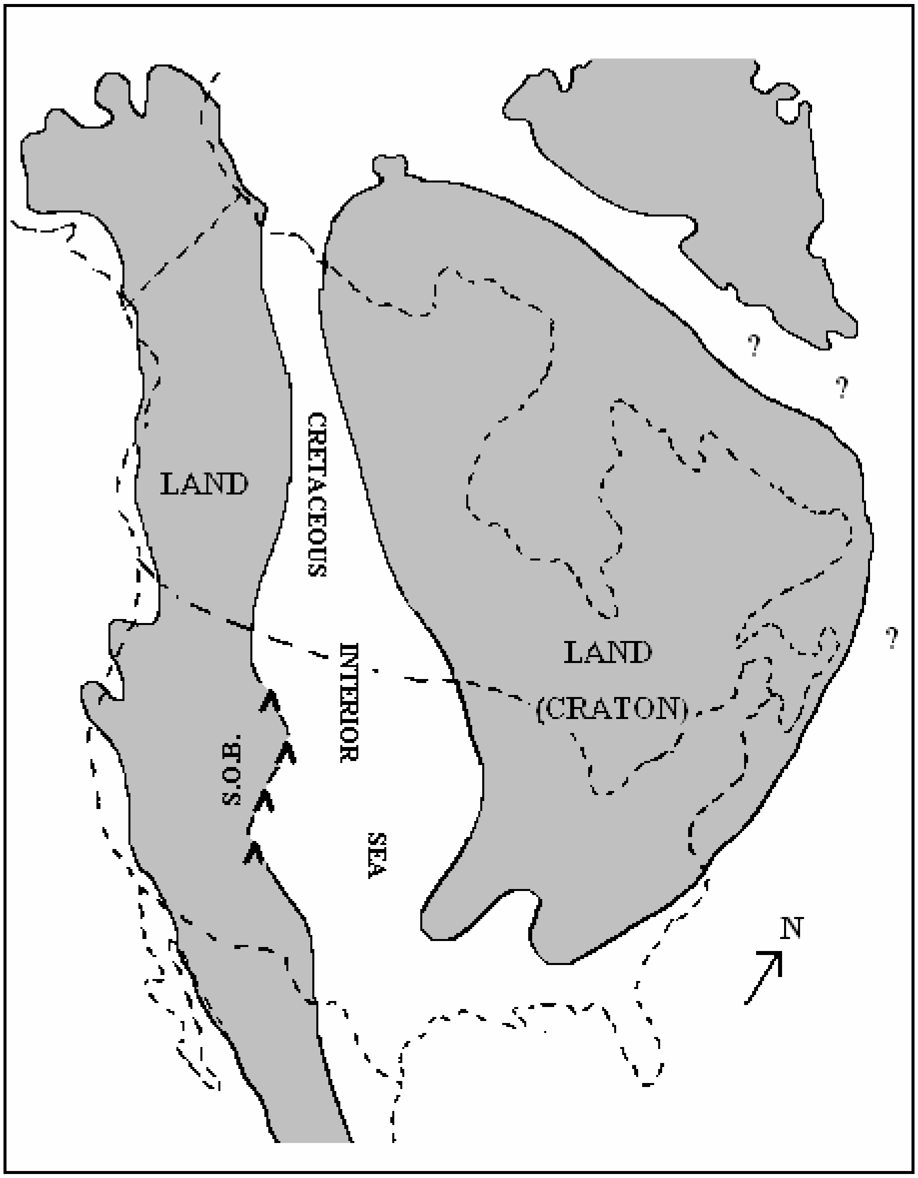

Figure 9. Location of the Cretaceous seaway. Shaded areas indicate land above sea level. "S.O.B." and inverted "V"s indicate the Mesozoic Sevier Orogenic belt. North indicates the Cretaceous north. Modified from Rice and Shurr (1983).

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This section provides a listing of references cited in this report. A more complete geologic bibliography is available and can be obtained through the NPS Geologic Resources Division.

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Appendix A: Geologic Map Graphic

The following page provides a preview or "snapshot" of the geologic map for Dinosaur National Monument. For a poster size PDF of this map or for digital geologic map data, please see the included CD or visit the GRE publications webpage: http://www2.nature.nps.gov/geology/inventory/gre_publications.cfm

Geologic Map of Dinosaur NM

The original maps digitized by NPS staff to create this product were:

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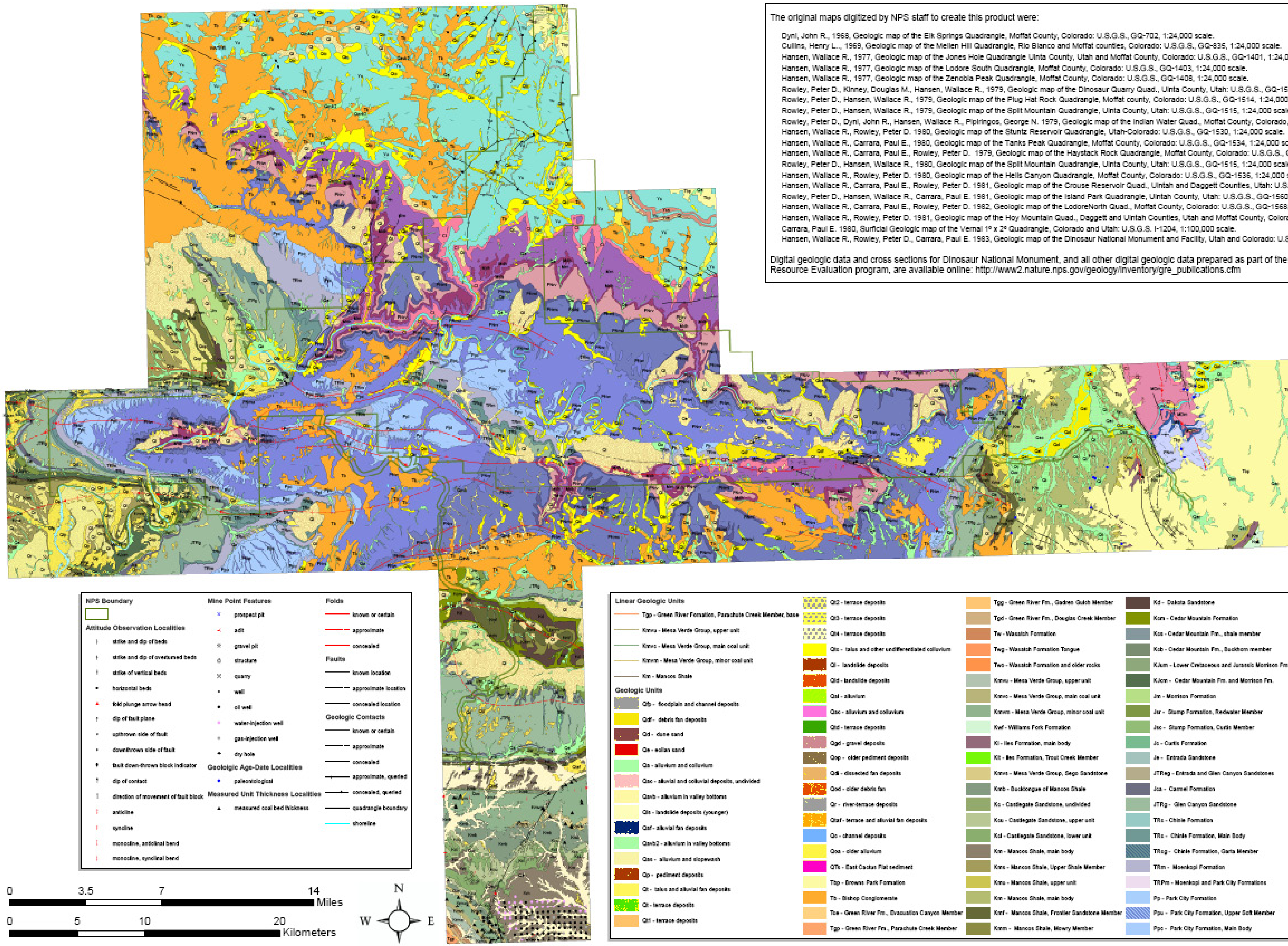
Digital geologic data and cross sections for Dinosaur National Monument, and all other digital geologic data prepared as part of the Geologic Resources Divisions Geologic Resource Evaluation program, are available online: http://www2.nature.nps.gov/geology/inventory/gre_publications.cfm



NPS Boundary

Attitude Observation Localities
- strike and dip of beds
- strike and dip of overturned beds
- strike of vertical beds
- horizontal beds
- fold plunge arrow head
- dip of fault plane
- upthrown side of fault
- downthrown side of fault
- fault down-thrown block indicator
- dip of contact
- direction of movement of fault block
- anticline
- syncline
- monocline, anticlinal bend
- monocline, synclinal bend

Mine Point Features
- prospect pit
- adit
- gravel pit
- structure
- quarry
- well
- oil well
- water-injection well
- gas-injection well
- dry hole

Geologic Age-Date Localities
- paleontological

Measured Unit Thickness Localities
- measured coal bed thickness

Folds
- known or certain
- approximate
- concealed

Faults
- known location
- approximate location
- concealed location

Geologic Contacts
- known or certain
- approximate
- concealed
- approximate, queried
- concealed, queried
- quadrangle boundary
- shoreline

Linear Geologic Units
- Tgp - Green River Formation, Parachute Creek Member, base
- Kmvu - Mesa Verde Group, upper unit
- Kmvc - Mesa Verde Group, main coal unit
- Kmvm - Mesa Verde Group, minor coal unit
- Km - Mancos Shale

Geologic Units
- Qfp - floodplain and channel deposits
- Qdf - debris fan deposits
- Qd - dune sand
- Qe - eolian sand
- Qa - alluvium and colluvium
- Qac - alluvial and colluvial deposits, undivided
- Qavb - alluvium in valley bottoms
- Qls - landslide deposits (younger)
- Qaf - alluvial fan deposits
- Qavb2 - alluvium in valley bottoms
- Qas - alluvium and slopewash
- Qp - pediment deposits
- Qt - talus and alluvial fan deposits
- Qt - terrace deposits
- Qt1 - terrace deposits
- Qt2 - terrace deposits
- Qt3 - terrace deposits
- Qt4 - terrace deposits
- Qtc - talus and other undifferentiated colluvium
- Ql - landslide deposits
- Qld - landslide deposits
- Qal - alluvium
- Qac - alluvium and colluvium
- Qtd - terrace deposits
- Qgd - gravel deposits
- Qop - older pediment deposits
- Qdi - dissected fan deposits
- Qod - older debris fan
- Qr - river-terrace deposits
- Qtaf - terrace and alluvial fan deposits
- Qc - channel deposits
- Qoa - older alluvium
- QTs - East Cactus Flat sediment
- Tbp - Browns Park Formation
- Tb - Bishop Conglomerate
- Tge - Green River Fm., Evacuation Canyon Member
- Tgp - Green River Fm., Parachute Creek Member
- Tgg - Green River Fm., Gadren Gulch Member
- Tgd - Green River Fm., Douglas Creek Member
- Tw - Wasatch Formation
- Twg - Wasatch Formation Tongue
- Two - Wasatch Formation and older rocks
- Kmvu - Mesa Verde Group, upper unit
- Kmvc - Mesa Verde Group, main coal unit
- Kmvm - Mesa Verde Group, minor coal unit
- Kwf - Williams Fork Formation
- Ki - Iles Formation, main body
- Kit - Iles Formation, Trout Creek Member
- Kmvs - Mesa Verde Group, Sego Sandstone
- Kmb - Bucktongue of Mancos Shale
- Kc - Castlegate Sandstone, undivided
- Kcu - Castlegate Sandstone, upper unit
- Kcl - Castlegate Sandstone, lower unit
- Km - Mancos Shale, main body
- Kms - Mancos Shale, Upper Shale Member
- Kmu - Mancos Shale, upper unit
- Km - Mancos Shale, main body
- Kmf - Mancos Shale, Frontier Sandstone Member
- Kmm - Mancos Shale, Mowry Member
- Kd - Dakota Sandstone
- Kcm - Cedar Mountain Formation
- Kcs - Cedar Mountain Fm., shale member
- Kcb - Cedar Mountain Fm., Buckhorn member
- KJum - Lower Cretaceous and Jurassic Morrison Fm.
- KJcm - Cedar Mountain Fm. and Morrison Fm.
- Jm - Morrison Formation
- Jsr - Stump Formation, Redwater Member
- Jsc - Stump Formation, Curtis Member
- Jc - Curtis Formation
- Je - Entrada Sandstone
- JTReg - Entrada and Glen Canyon Sandstones
- Jca - Carmel Formation
- JTRg - Glen Canyon Sandstone
- TRc - Chinle Formation
- TRc - Chinle Formation, Main Body
- TRcg - Chinle Formation, Gartra Member
- TRm - Moenkopi Formation
- TRPm - Moenkopi and Park City Formations
- Pp - Park City Formation
- Ppu - Park City Formation, Upper Soft Member
- Ppc - Park City Formation, Main Body
- Pw - Weber Sandstone
- PNm - Morgan Formation
- PNmu - Morgan Formation, Upper Member
- PNml - Morgan Formation, Lower Member
- PNrv - Round Valley Limestone
- Mdh - Doughnut Shale and Humbug Formation
- Ms - Shale and Dolomite
- Mm - Madison Limestone
- MDm - Madison Limestone and older rocks
- OCd - Dike
- Cl - Lodore Formation
- Yu - Uinta Mountain Group, Sandstone
- Yus - Uinta Mountain Group, shale and sandstone
- Yus4 - Uinta Mountain Group, Unit 4
- Yus3 - Uinta Mountain Group, Unit 3
- Yus2 - Uinta Mountain Group, Unit 2
- Yus1 - Uinta Mountain Group, Unit 1
- Water

0 3.5 7 14 Miles

0 5 10 20 Kilometers

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Produced by Geologic Resources Division

February 2006

Appendix B: Scoping Summary

The following excerpts are from the GRE scoping summary for Dinosaur National Monument. The scoping meeting occurred August 10- 11, 1998; therefore, the contact information and Web addresses referred to herein may be outdated. Please contact to the Geologic Resources Division for current information.

Workshop Summary

An inventory workshop was held at Dinosaur National Monument on August 10- 11, 1998 to discuss the monument's geologic resources and associated issues and needs. In all, fifteen cooperators participated in the two- day workshop. The list of participants can be found at the end of this section.

Field Trip

In the morning of the first day of the workshop, Wallace Hansen, who mapped most of the Dinosaur area before retiring from the USGS, led a field trip for many of the cooperators. The group traveled to Harpers Corner to discuss the stratigraphy, structure, and geomorphology of the monument. Along the Harpers Corner road, the group stopped to discuss areas of unstable roadway due to slumps and landslides.

In the afternoon, the field trip visited the Green River District of the monument. The Dinosaur NM Chief of Maintenance, explained stabilization work that will be done along the bank of the Green River near the park entrance, where the river has been actively eroding its cut bank into the road base that was constructed in the Mancos Shale slope. At Cub Creek, where the road crosses the stream, the group discussed the historic channel incision and recent high flows and sedimentation that create numerous problems for road maintenance. The trip ended with a hike from Josey Morris Ranch to Hog Canyon to view and discuss a stream restoration project that was done to benefit the Ute Ladies- Tresses Orchid, a federally listed rare plant. Steve Petersburg explained that the restoration project has raised the local water table in Hog Canyon, which is a relatively short box canyon eroded into the Weber Sandstone. The increased height of the water table and exclosure of cattle has allowed for recovery and thick riparian growth of vegetation on the canyon floor, but has given limited results for increasing the population of the rare orchid, which appears to grow best on periodically disturbed areas.

Workshop Meeting

After introductions by the participants, Bill Dye and Gary Mott of Dinosaur NM maintenance took the group on a tour of the Dinosaur Quarry Visitor Center to show the extent of the damage caused by movement of the substrate beneath the building. Issues with the visitor center building are discussed in more detail in the Hazards section.

Joe Gregson, I&M geologist/information manager, presented an overview of the NPS I&M Program, the status of the natural resource inventories, and the geological resources inventory. Bruce Heise, NPS GRD geologist, followed with an overview of the organization of the Natural Resource Stewardship and Science Washington Office, GRD, and the Colorado pilot project.

Dan Chure, park paleontologist, gave the group a tour of the Jurassic quarry and discussed the instability of the exposed Morrison Formation and fossils. Dan also took the group just east of the Quarry Visitor Center to show and discuss unstable mass wasting conditions associated with the historic quarry office that had been constructed by Earl Douglas.

Christine Turner and Fred Peterson, USGS geologists, gave an overview and discussed important results of the Morrison Initiative, which was an intensive, multidisciplinary research project that comprehensively studied the Morrison Formation associated with paleontological sites throughout the west. Much of the Morrison Initiative work was done in NPS units, and Dan Chure played a key role in its success.

After lunch, Ann Elder and Scott Madsen, park museum specialists/paleontologists, gave the group a tour of a new dinosaur quarry site (2 Sauropods) located west of the Quarry Visitor Center in the Lower Cretaceous Cedar Mountain Formation that is an important faunal locality for this time period.

Tamara Naumann, park botanist, discussed the association of rare plants with certain geologic strata and geomorphic surfaces. Tamara shared issues about the Ute Ladies- Tresses Orchid, a federally listed threatened plant that occurs in the monument with significant populations in Lodore Canyon.

The remainder of the meeting was devoted to discussing the status of geologic and paleontologic mapping at Dinosaur as well as resources that could contribute to a geologic report about the monument.

Hazards

Several hazards were discussed that affect the monument- - especially the maintenance of park roads and buildings. Most of the hazards were associated with slope or substrate instability and mass wasting events.

1. Along the Harpers Corner road, slumps in existing landslide materials (mostly derived from the Jurassic Morrison Formation) create maintenance and traffic hazards in several areas. Dinosaur NM Maintenance is considering relocating the roadways to the crests of associated ridges to help alleviate the slumping problems.

2. Along the quarry entrance road near the park boundary, the Green River has been actively eroding its cutbank into the road base that was constructed into the Mancos Shale slope. Dinosaur NM maintenance has a project in work that will fill in the eroded areas and armor the bank with riprap to protect the road for a time. The hazardous location of the road, unstable Mancos badlands above, and Green River erosion below, were discussed. The only permanent solution may be to move the road to the opposite bank of the Green River, which has its own set of engineering and political issues.

3. At Cub Creek where the road crosses the stream, the creek has incised several meters into the older valley fill deposits. Upstream of the road crossing, recent beaver dams may be restoring the riparian zone and arresting the entrenchment, but this spring, high stream flow eroded around the end of a beaver dam and directed the stream against the road embankment. Dinosaur NM maintenance had to breach the beaver dam to get the stream flowing back into its main channel and through the culvert under the road. Subsequently, Dinosaur NM maintenance placed riprap to armor the upstream portion of the roadbed, but the stream rapidly silted in upstream of the barrier, indicating that although entrenched, the stream is still moving significant sediment. This problematic area could benefit from a comprehensive study of the hydrology and geomorphology with the goal of restoring the pre- entrenchment channel geometry and fluvial regime.

4. The relocation of the Echo Park campground was discussed. The existing campground is located on the cutbank of the Green River just below its confluence with the Yampa River in the bend of the river around Steamboat Rock. Dinosaur NM maintenance personnel indicated that tentative plans were to relocate the campground back from the river on the west side of the Pool Creek canyon to take advantage of the tree cover. It was noted that the close proximity of a side canyon and Pool Creek to west side area has a greater risk for flash floods and debris flows than would a location on the east side of the creek and canyon (where, unfortunately, there is no tree cover).

5. The Quarry Visitor Center has undergone major damage due to expanding, contracting, and shifting substrate beneath the building. Although the quarry face appears to be somewhat stable, the central part of the structure appears to be sinking and significant offsets of several inches to a foot or more are readily apparent in many areas of the building. The obvious floor deformation and tilting of support beams and windows suggest that the structural integrity of the building may be in jeopardy. The site location is on the Morrison Formation, which dips about 50 degrees toward the south. The Morrison contains abundant smectitic clays called bentonite, which swell and contract greatly with changes in fluid content. Dinosaur NM maintenance has isolated plumbing in the building and kept the roof in good condition to limit the amount of water that can infiltrate under the building, but the deformation continues. Also, Dinosaur NM maintenance has reinforced the spiral walkway but must also continually monitor the freestanding structure for movement. Deformation and ground movement are also readily apparent in the parking lot and sidewalk outside of the building. Dinosaur NM maintenance has received some engineering review from the Denver Service Center, but a comprehensive engineering study has never been undertaken. The quarry building is considered a historic structure, so approval must be obtained for any architectural modifications. Dinosaur staff expressed the need for major reconstruction of the quarry building, and all of the cooperators concurred. Although building renovation is well outside the scope of the geologic resources inventory, it is recommended that the ongoing deformation of the quarry building and surrounding area should be studied and that a major engineering review to address the structural problems is needed.

6. Without discussing the details, Dinosaur staff noted that similar, but less severe, foundation- movement issues exist at the headquarters building.

7. Although not specifically discussed, a geologic hazards map is needed for park planning and maintenance.

Research Needs

1. Tamara Naumann, Dinosaur NM botanist, discussed the association of rare plants with certain geologic strata and geomorphic surfaces. The Uinta Basin has 30- 40 endemic plant species of which 15- 20 occur within Dinosaur NM. Tamara shared issues about the Ute Ladies- Tresses Orchid, a federally listed threatened plant that occurs in the monument with significant populations in Lodore Canyon. In the canyon, the rare orchids grow somewhat abundantly and show a strong correlation with geomorphic surfaces formed under the flow regime established by discharge from the Flaming Gorge dam. J.C. Schmidt and Paul Grams (who mapped the geomorphic surfaces in Dinosaurs canyons) of Utah State University assisted with the orchid inventory. A significant issue is that increased flows from Flaming Gorge have been proposed to assist the recovery of endangered fish in the Green River, but the increased flows might endanger the new- found orchid population. Analysis of existing data is in progress, and further research is needed to determine the effect of flooding on the existing surfaces and plants, as well as, how and if higher flows might create new habitat for the orchid in areas such as Brown's Park. The research

will assist with the preparation of a mitigation plan that could help both the orchids and fish.

2. During the discussion of the Morrison Initiative and while visiting the Lower Cretaceous dinosaur dig, it was noted that a comprehensive, multidisciplinary study of the Cedar Mountain and correlative formations would give significant understanding of the paleoenvironments of that time period. New research might include detailed sedimentology, stratigraphy, palynology, pedology, as well as invertebrate and floral paleontology. Understanding of the new quarry site in the Cedar Mountain Formation and its fossils would be greatly enhanced by such a study.

3. Although the present quarry preparation facilities are quite good, several problems exist for long- term preparation and curation of specimens. The present facility is located in the Quarry Visitor Center with its structural building problems discussed earlier. In addition, specimen storage facilities are inadequate for the ever- growing collection. Working collections are stored at the quarry site, but others are stored in sheds or the basement of the headquarters building more than 20 miles away. Improperly ventilated storage facilities make working with radioactive specimens (that contribute to the buildup of radon gas) a hazardous task. Dinosaur NM staff proposed that a new building should be constructed at another, more stable site. The new building would provide infrastructure for collection preparation and curation, scientific research, resource management, as well as inventory and monitoring activities—all under one roof.

4. As mentioned above, a study of the hydrology and geomorphology of Cub Creek in conjunction with planning for a stream restoration project would assist with continual road maintenance problems in that area.

5. Wallace Hansen suggested that two very large juniper trees in Yampa Canyon, that may be record trees measuring 144" and 120" in circumference, should be cored to get their age and a climate record. Trees of this size may be 2000 or more years old. Tamara Naumann agreed to do the project. Wallace also suggested that vandalized rock art could be retouched, and the group concurred.

Interpretation

Although specific interpretive issues were not discussed in detail, several resources associated with geology were noted.

1. Christine Turner and Fred Peterson of the USGS are working with other researchers on a comprehensive report for the Morrison Initiative. They think that after completion of the comprehensive scientific report that a summary report of the important results will be written for Dinosaur NM and the general public.

2. Christine Turner and Fred Peterson also discussed earlier work for a professional society geologic guidebook and road log that linked Permian formations among various parks and other sites for the Colorado Plateau. Geologic guidebook road logs have also been discussed at other workshops as an overarching interpretive theme among parks.

3. Several interpretive publications related to geology are available for Dinosaur NM. A comprehensive geologic map of Dinosaur NM has been compiled and published (Hansen, Rowley, and Carrara, 1983) and is for sale in the monument bookstores. A river runner's guide (Hansen, 1993), that is published by the Dinosaur Nature Association and that explains the general geology of the monument quite well, is also for sale. A USGS Professional Paper and Rocky Mountain Association of Geologists paper about the Eastern Uinta Mountains (both by Hansen, 1986) are available but not for sale. Other resources by the Untermanns and Don Stone are also available but not sold in the bookstores. A generalized geology publication for Dinosaur NM would make a useful interpretive addition to the existing publications.

Maps

1. Geologic Maps. Due to the extensive work by Wallace Hansen and his colleagues, the geology of the Dinosaur area has been well mapped. Fifteen 1:24,000 and several smaller scale maps, including a 1:50,000 scale Dinosaur National Monument map (Hansen, Rowley, and Carrara, 1983), exist for the area. At the subsequent map evaluation meeting at the USGS in Denver, stable- base source maps will be sought for developing a digital geologic coverage for the park. Several in the group had heard about the existence of scanned versions of the Dinosaur NM maps, but no one knew of their status. Michele Gudorf of the Intermountain Region GIS group was contacted, and only part of the existing map coverage is available and that is probably in an old version of GRASS GIS and will not be useable for the inventory map products. Michele is sending a copy of the data to the I&M Program in Fort Collins for evaluation.

2. Paleontologic Maps. Dan Chure discussed the fact that no complete maps showing the locations of the quarry sites and fossil locations currently exist. Source maps of the Carnegie, Smithsonian, and University of Utah quarry activities are available, and a National Science Foundation grant has been acquired to compile a comprehensive map and database of the fossil attributes and locations. A contractor(?) in Salt Lake City is compiling the map and database of more than 4000 records that document more than 400 fossil animals. A multimedia demonstration project is also in work that will combine photos, drawings, literature, citations, etc. into an interactive visitor display. The Carnegie Museum wants to publish the completed map for sale.

3. GIS Data. The cooperators discussed that some GIS data had been developed for the monument and that other base cartographic data should be available from the I&M Program, the Intermountain Region GIS staff,

and Moffat County (DOQQs). The I&M Program has DLG, DEM, DRG, and DOQ data available on CD-ROM, so Moffat will not be contacted. The Intermountain Region GIS staff has the partial geologic raster map(s) and a coarse vegetation coverage available. The geomorphic surfaces coverage may be available from Paul Grams of Utah State University.

4. GIS Needs. Dinosaur NM does not currently have an operational GIS. Since Dinosaur does not have a FTE to dedicate for a GIS Specialist position, the best alternative is to acquire a desktop GIS system (i.e., Arcview GIS) that the scientific and resource management staff could use to support their research, inventory, and monitoring activities. The I&M and Intermountain Region GIS Programs should be able to assist Dinosaur NM staff with setting up a GIS system for the park.

Report

Several geologic reports already exist that cover the Dinosaur area quite well as discussed in 3 under Interpretation above. The consensus of the group was that a synopsis of the existing material could be compiled for the geologic inventory report. Paleontology (Dan Chure), hazards, data, and other sections will be compiled and written by GRD and I&M staff as needed.

ACTION ITEMS

1. Joe Gregson will check for available digital base cartographic and other GIS data that is available for Dinosaur NM (DONE, 9/18/98).
2. Obtain stable- base geologic map masters from USGS for digitizing.
3. Digitize, attribute, and develop GIS for Dinosaur NM geologic maps.
4. Compile, edit, and distribute a Dinosaur NM geologic report.
5. Establish a GIS system for Dinosaur NM (I&M and IMR will assist with data). Dinosaur NM staff should propose an Arcview GIS system for funding by the IMR GIS FTSC (Teresa Ely). (**Need to identify at least one Dinosaur NM NR staffer to take the lead for this desktop GIS.)
6. Geologic hazards map. Check with states of Colorado and Utah for any existing data. Assess feasibility of developing hazards map for park GIS.
7. Abandoned mine lands inventory. Review topographic maps for locations of mine adits and shafts. Develop GIS coverage and AML data records if possible.
8. Develop paleontological themes for park GIS (DINO/USGS/IMR projects).
9. Archive Dinosaur NM research library materials into NRBIB Procite database. Vince Santucci has contacted Scott Palowski, archivist at Yellowstone N.P. about a detail to assist with this project.
10. Conduct a cave inventory (unique geologic features). Inverviews with Dinosaur NM staff provided information about several caves in the monument. Identified caves include Whispering, Signature, Mantell, Interstate, and Cave of Logs. Copies of reports were forwarded to Ron Kerbo of NPS GRD.

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Dinosaur National Monument

Geologic Resource Evaluation Report
NPS D-217, March 2006

National Park Service

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Natural Resource Stewardship and Science

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